MOTOR CAR MECHANISM

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MOTOR CAR MECHANISM

BY

W. E. DOMMETT, A.M.I.A.E.
WHITWORTH EXHIBITIONER, ADMIRALTY PRIZEMAN, LECTURER IN
ENGINEERING AT KINGSTON-ON-THAMES TECHNICAL INSTITUTE,
AUTHOR OF "PETROL ENGINE CONSTRUCTION AND DRAWING"

WITH 102 ILLUSTRATIONS

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PREFACE.

WHEN starting the Motor Car Engineering Class at Guildford Technical Institute the author got together some lecture notes which form the basis of the present book. It is intended as an Elementary Textbook for those students who want a general knowledge of motor car construction of the present day, and who intend to take the allied subjects of Mechanics, Mathematics, and Machine Design. Examples of types have been given, no attempt being made to an exhaustive study of every piece of apparatus put forward by the manufacturers for public approval and use.

The student is advised to make sketches, fully dimensioned, to supplement those in the book, and he could profitably refer to Volume IV. of this series on "Toothed Gearing" when reading chapters XV. and XVI. The necessarily brief reference to ignition matters in chapter IX. should be supplemented by a book dealing exclusively with the subject, such as "Magneto and Electric Ignition" by W. Hibbert (Whittaker & Co.).

The author desires to express his thanks to Humber Cars, Ltd., for the loan of blocks for the frontispiece, and Figs. 49, 77, 81, 85, 90; to S. Wolf & Co., Southwark St., E.C., for blocks for Figs. 52, 53, and also to the students who made the drawings for the remaining figures.

The author desires also to put on record his grateful appreciation of the work done by Mr. S. Batstone, A.M.I.E.E., in reading the manuscript and making valuable suggestions.

W. E. DOMMETT.

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CONTENTS.

CHAPTER I.

PAGE

THE CAR 1

CHAPTER II.

THE ENGINE 6

Cycle of Operations 7

The Four-stroke Cycle 7

The Cylinder 8

The Crank Case 10

The Pistons 11

Connecting Rods 15

Fly-wheels 18

Starting Handle and Apparatus 18

Complete Engine 20

CHAPTER III.

PROPERTIES OF GASES 21

Projected Area of the Piston 26

CHAPTER IV.

BRAKE HORSE-POWER, DYNAMOMETERS, EMPIRICAL FORMULA FOR HORSE POWER, AND MECHANICS PROBLEMS 30

Empirical Formulæ 32

Forces acting on the Piston due to Acceleration of the Reciprocating Parts 33

Correction of the Indicator Diagram 34

Energy Stored in the Fly-wheel 37

Exercise 38

CHAPTER V.

PAGE
VALVES: CONSTRUCTION, ARRANGEMENT, AND ACTUATION . . . 39
Poppet Valves 39
Arrangement 41
Cams 42

CHAPTER VI.

VALVES: SLEEVE, ROTARY PLUG, PISTON, ROTARY DISK, MAIN PISTON ACTING AS A VALVE . . . 49
Sleeve Valves 49
Rotary Plug 52
Piston Valves 55
Disk Valves 55
Valveless Engines 56

CHAPTER VII.

FUELS AND CARBURETTERS 60
Carburetters 63
Symptoms 74

CHAPTER VIII.

LUBRICATION AND LUBRICATING SYSTEMS 76
Splash 76
Pressure or Mechanical 78
Combined Splash and Pressure 79
Lubricating Pumps 79

CHAPTER IX.

MAGNETOS AND ACCUMULATORS 82
Cutting off Ignition 87
Safety Spark Gap 87
Contact Breaker 87
Locating Troubles 88
Accumulators 89

CHAPTER X.

PAGE
COOLING SYSTEMS 91
Air 91
Water Cooling 91
Thermo Syphon Circulation 94
Radiators 95
Tube 95

CHAPTER XI.

TRACTION 98
Adhesive Power 98
Tractive Force 100
Resistance to Motion 101
Brakes 101

CHAPTER XII.

FRAMES AND SPRINGS 103
Springs 106
Front Springs 108
Rear Springs 108
Supplementary Springs 110

CHAPTER XIII.

FRONT AXLES, STEERING GEAR 111
Wheel Mountings 113
Linkages 113

CHAPTER XIV.

CLUTCHES 119
Multiple Disk Clutches 124

CHAPTER XV.

SPEED GEARS AND BRAKES 126
Epicyclic Gear 130
Brakes 130
Countershaft Brakes 131

h

CHAPTER XVI.

PAGE
THE BACK-AXLE, CARDAN SHAFT, RADIUS RODS, TORQUE RODS, ETC. 133
Radius Rods 138
Torque Rods 138
Chain Drive 138

CHAPTER XVII.

STEAM CARS 140
Steam Generators 141
The Engine 145

CHAPTER XVIII.

OTHER TRANSMISSION SYSTEMS 153
Friction Drive 153
Hydraulic Transmissions 155
Petrol Electric System 158
Electric Transmission 158
Complete Electric Installation 158

APPENDIX.

CITY AND GUILDS SYLLABUS IN MOTOR CAR ENGINEERING 161

Ordinary Grade.

PETROL CAR 161
Engines 161
Petrol 161
Carburation 161
Tractive Force 161
Carburetters 161
Speed Gears 161
Steering Gear 162
Clutches 162
Cooling 162
Lubrication 162
Readjustments 162

PAGE
Transmission . . . 162
Chassis . . . 162

ELECTRIC IGNITION . . . 162
Ignition . . . 162
Electro-Magnetic Induction . . . 162
Induction Coil . . . 162
Wiring . . . 162
Magneto-Ignition . . . 162

STEAM CARS . . . 162
Steam Generators . . . 162
Burners and Fuels . . . 162
Boiler Feed-Pumps . . . 162
Automatic Systems . . . 163
Condensers . . . 163

ELECTRIC CARRIAGES . . . 163
Motors . . . 163
Controllers . . . 163
Transmission . . . 163
Cut-outs . . . 163

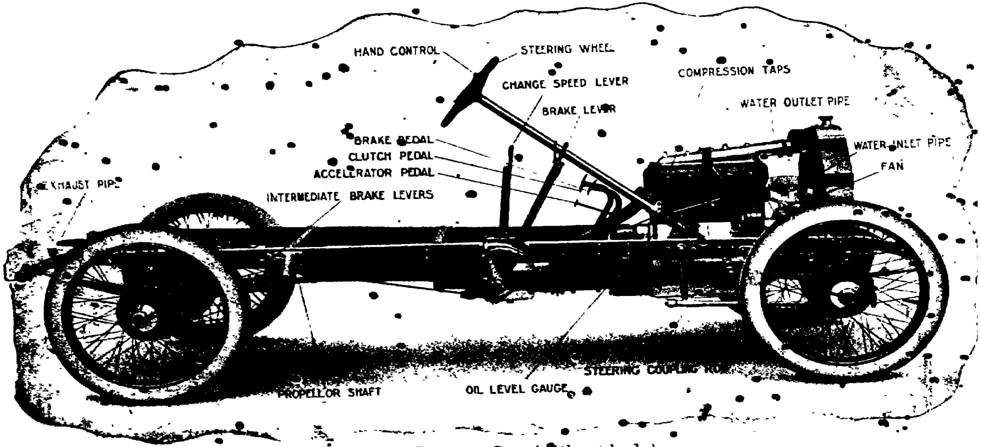
GARAGE SYSTEMS . . . 163

MOTOR CAR ENGINEERING EXAMINATION PAPER . . . 163

TABLES—

Logarithms . . . 167
Antilogarithms . . . 171
Trigonometrical Functions . . . 175
Squares, Cubes, etc. . . . 177
Areas and Circumferences of Circles . . . 183
Metric Equivalents . . . 185
Equivalent Values of Millimetres and Inches . . . 186
Kilogrammes in Pounds . . . 187
Properties of Saturated Steam . . . 188

INDEX . . . 191



11·9 h.p. Humber Car (without body).

MOTOR CAR MECHANISM

CHAPTER I.

THE CAR.

BEFORE going into details, a brief summary of the principal elements which constitute the modern motor car, and the manner in which they are arranged relative to one another will be given.

Let us assume that we are standing at the side of the car pictorially illustrated in the frontispiece, then the line drawings of the same car of which Fig. 1 gives a side elevation (the near side wheels being off), and Fig. 2 a plan (the dashboard being absent), can be more easily read and the following description more readily grasped. The drawings are those of an 11·9 Humber car, this example being chosen as representative of the best British practice.

The photo and figures represent what is technically known as the *chassis*, which can best be defined as a complete motor car less the body work.

Proceeding now to enumerate the parts, A is the frame work which is supported or mounted through springs *s* on the front and rear axles *m*, *n*, which are in turn supported by the wheels *w*. Upon this frame are the *power plant*, the *transmission gearing*, and *controlling mechanism.*

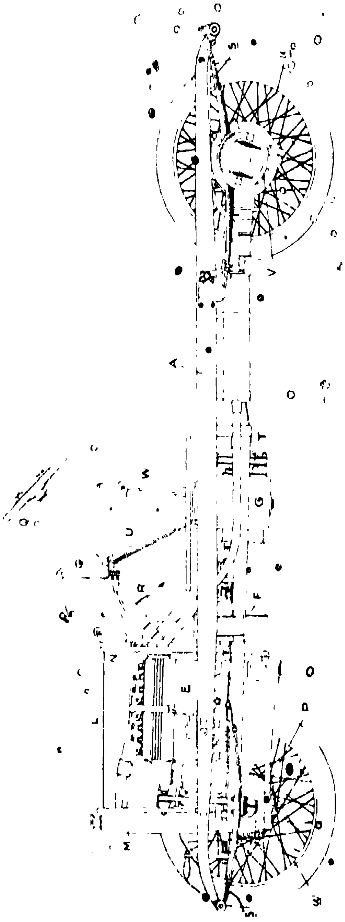


FIG. 1.—Side elevation, Humber chassis.

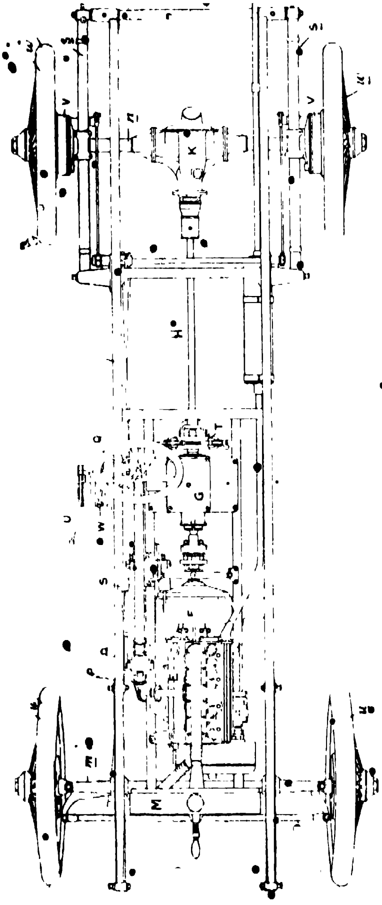


FIG. 2.—Plan of Humber chassis.

The car is fitted with an internal combustion engine E from which the energy for propelling the vehicle is obtained. This power is transmitted by a clutch F to a gear box G, and thence by a shaft H, and gearing enclosed in the casing K to cross shafts which drive the rear road wheels.

The clutch is fitted so that under circumstances which require it, such as when changing gear, the engine can be disconnected from the transmission gearing. The gears in the box G are used for altering the ratio of the revolutions of the engine relative to the revolutions of the shaft H and road wheels, the necessity for this fitting arising from the fact that below certain speeds the power generated by an internal combustion engine falls off very rapidly. The gearing in the casing K is known as the differential or balance gearing, and it not only connects the shaft H to the shafts of the road wheels *w*, but also enables the power taken by and revolutions of the wheels to be automatically controlled when the car is proceeding along a curved track.

The engine and its component members, such as the magneto, carburetter, lubricator pump, water circulating pump and fan, are housed under a cover L known as the "bonnet". This cover extends from the radiator M, which contains the cooling water for the engine E, to the dashboard N.

The direction in which the car is moving can be maintained or altered by means of a steering gear P which couples the hand wheel Q to the front wheels. Other controlling members required are a foot pedal R for manipulating the clutch, a foot pedal S for actuating the brake T which is on the driving shaft immediately in the rear of the gear box, a hand lever U which actuates the brake V attached to the rear road wheels, a hand lever W for altering the gears, and certain levers both hand and foot operated, which are coupled to various fitments of the engine. Although the description given is that of a very common type, there are of course instances of variation which are largely due to the requirements arising from the character of the work the car is called on to perform. For example, in the heavier and higher-powered cars used for commercial purposes it is not unusual to find the differential and transverse shafts mounted on the gear box, the shafts being coupled by chain and sprocket gearing with the two rear road wheels. In another form and usually with lighter and lower-powered cars, the final transmission element comprises a single chain coupling the gear box shafting with the differential.

When other forms of power plant using steam or electricity are fitted the arrangement of parts may differ considerably from that described in connexion with the internal combustion engined car, but as the number of such cars is relatively small the chapters dealing with the details of parts will also include the arrangement of those parts.

CHAPTER II.

THE ENGINE.

An internal combustion engine is made up of a number of moving and stationary parts, in the former class being the piston, connecting rod, and valves; and in the latter, cylinder, crank case, and fuel-supplying and ignition devices. The net result of

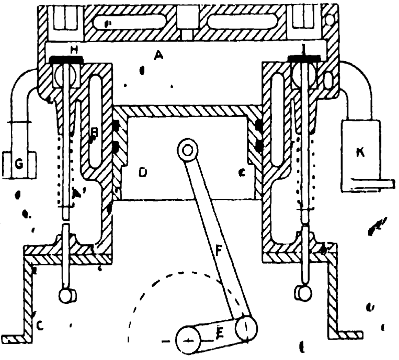


Fig. 3.

these parts properly functioning together is the development of power in the rotating crank shaft which can be coupled up for yielding useful work.

A diagrammatic view of such an engine is given in Fig. 3, the cylinder A has a water jacket B and is mounted on the upper half of the crank case C. In the cylinder reciprocates a piston D which is coupled to the crank shaft E by a connecting rod F. An inlet valve H controls the passage of fuel from the induction pipe to the cylinder, and an exhaust valve I the flow of used gases from the cylinder. Upon the induction pipe is mounted the fuel-supplying device or carburetter G, and on the exhaust pipe a silencer K.

Cycle of Operations.—When a number of parts co-act so that a certain set of operations are being continuously repeated, each set of operations is known as a "cycle," and the time taken to perform this cycle is known as the "period".

In the internal combustion engine a complete cycle may occur during every four strokes of the piston, or during only two. In the first case the cycle is known as the four-stroke, or the "Otto," this latter being a name of the designer of the first really successful engine working on this principle. The other cycle is known only as the two-stroke cycle. An engine on the one-stroke cycle has been constructed, but its manufacture was not put on a commercial basis and no development in this direction of any merit has occurred since.

The Four-Stroke Cycle.—Assuming the piston D, Fig. 3, to be at the top of the cylinder and just starting to move down, that the exhaust valve is closed and that the inlet valve is open, as the piston moves it draws in the charge of mixed fuel and air from the carburetter G and performs what is known as the *suction stroke.* At the bottom of the stroke the inlet valve H is closed. During the ensuing up stroke, the piston compresses the charge into a space at the top of the cylinder and performs the *compression stroke.* It may here be noted that when the free space above the piston is of minimum volume, this is called the "*clearance volume*". When the piston arrives at the top of the compression stroke, the compressed mixture is fired by the sparking plug, and the resulting explosion forces down the piston which performs its *power* or *explosion stroke.* On the next up stroke, and the exhaust valve I being open, the burnt gases are forced out of the cylinder, the piston performing the *exhaust stroke.* The cycle of operations then starts again to proceed in like manner all the while the engine is acting properly.

The Cylinder.—Made of close-grained cast iron, each cylinder is turned in a lathe and ground on its interior cylindrical surface so that it is extremely smooth and the same diameter all along. The upper part is however made slightly larger, so that the piston cannot wear the cylinder to leave a ridge. Valve pockets and a water jacket are also provided, as already shown in the cylinder outlined in Fig. 3. In some cases the combustion head is not cast in one with the rest of the cylinder, neither is it universal to form the outer walls of the water jacket integral therewith. Among the advantages of a separate head, is the ease with which the piston head can be got at for cleaning. Another advantage is that the surface of the cylinder wall on the water jacket side can be turned, in consequence of which a more efficient cooling is obtained and a more uniform thickness of wall lessens the internal strains when warmed up.

A single cylinder casting is illustrated in Fig. 4, from which some idea of the complexity and arrangement of the parts of the casting can be obtained.

In modern cars the engine usually has four cylinders which can be arranged in one of three ways: (*a*) four separate cylinders, (*b*) cylinders cast in

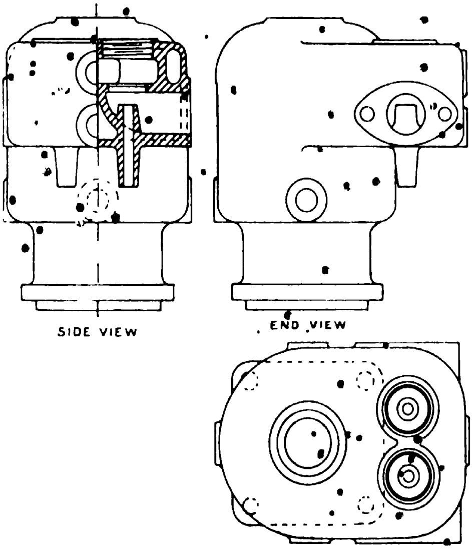


FIG. 4.—Single-cylinder casting, with valves on one side.

pairs, (*c*) all four cylinders in one casting, a method known as the monobloc. In deciding which system to adopt the designer has to consider a large number of points, for example when separate units are used any defect arising in one unit can be cheaply and easily remedied, whilst any defect in a monobloc casting means scrapping the whole lot. This disadvantage does not need so much consideration however, now that the art of welding has been brought to such a high pitch. If more than one type of engine is being made the same units can be used in a two-, four- or six-cylinder engine, the number of patterns and tools used being reduced to a minimum. Against this advantage is the fact that the weight of and overall length of such an engine are increased as compared with the monobloc arrangement. A not unimportant point to consider is the number of pipe joints required, the arrangement of the piping, and also such matters as the number of bearings it is desired to support the crank shaft in. At the end of the chapter, in Fig. 11, the four-cylinder engine illustrated is made up from two sets of castings each containing a pair of cylinders.

The Crank Case.—This is usually of aluminium and formed in two parts, of which the upper part is attached to the frame of the chassis or to a sub-frame, and carries the main crank shaft bearings, whilst the lower part practically acts only as an oil container, which is the case with the engine shown in Fig. 11.

The upper part is suspended from the frame at three points, so that it does not become distorted when the car is moving over uneven ground.

When plain bearings are used they are generally of gun-metal or phosphor bronze and sometimes lined with white metal or other anti-friction material. There is an advantage in lining the bearing in this respect that instead of the crank shaft seizing with consequent bad results to the engine when the lubricating system fails, the lining itself melts and warning is thereby given. In more recent practice, ball bearings have been successfully employed, those of the double row self-aligning type, such as the Skefko, being eminently satisfactory. As will be noticed in the drawing of a journal bearing, the outer race is spherical with centre at the centre of the bearing and is common to both sets of balls.

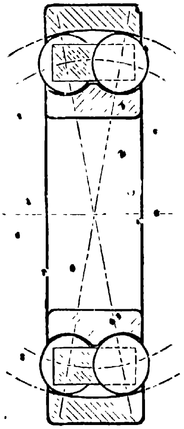


FIG. 5.—Self-aligning ball bearing, Skefko.

An entirely different design, for which a good deal can be said, is that in which a barrel-shaped casting is used, two circular end plates carrying the front and rear bearings.

The Pistons.—Trunk pistons are used and generally made of cast iron, but some makers now use pressed steel, with a consequent saving in weight. Not only is the weight reduced but the problem of balancing and inertia, to which attention has to be paid if one desires to produce a vibrationless engine, becomes much easier. The length is from one to one and a quarter times the diameter, and the thickness of the head about seven-hundredths. The tops are either concave, convex, or flat, the choice being governed by the volume of compression space required more than anything else, although it has been found that concave tops are more liable to form a sooty deposit. Webs may be formed on the inner surface of the top of the head for assisting in radiating the heat, strengthening the head, and for collecting and directing lubricating oil to the gudgeon pin.

Under working conditions, the temperature of the top of the piston is higher than that of the bottom and also than that of the cylinder walls; it is therefore necessary to provide for unequal expansion, the method adopted consisting in tapering the piston above the gudgeon pin and making the smallest diameter less than that of the cylinder by three-thousandths of an inch per inch of cylinder diameter.

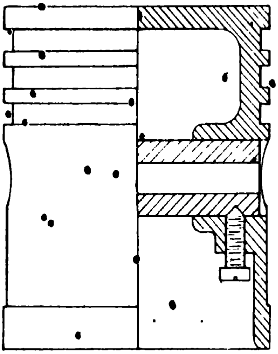


Fig. 6. Trunk piston.

In Fig. 6 is illustrated a flat-topped piston of diameter 3½ inches. The head is ¼ inch thick, the side walls above the gudgeon pin $\frac{7}{16}$ inch, and below the pin the walls taper to $\frac{3}{16}$ inch. In Fig. 11 the pistons are shown with a domed top.

For the sake of lightness and more particularly for use on racing cars, holes are drilled around the lower part or *skirt* of the piston and two rings only may be used. It is, however, customary to fit three or four rings.

The rings are situated above the gudgeon pin as a rule, but the lowest one is sometimes placed at the bottom of the skirt, which is made of greater thickness so that the necessary groove can be turned in it. In order that the rings shall press evenly on the cylinder walls, they are turned eccentrically out of cast-iron hollow cylinders, and about $\frac{1}{100}$ inch large; a diagonal cut or slot is then made to give $\frac{1}{100}$ inch play.

When assembling, care should be taken to see that these cuts or slots are not in one line or else leakage past the rings will take place. The leakage will be of two kinds, in the first place gas will pass down with a loss in compression and power, and secondly lubricating oil will be drawn up on the suction stroke and carbon deposits quickly appear on the piston and head of the cylinder. These *deposits* are not such good heat conductors as the metal piston, so that the temperature is higher on a dirty piston than it is on a clean one. If the temperature is sufficiently high, the compressed charge may become ignited before the spark occurs at the plug. This pre-ignition, occurring as it does before the piston reaches the top of the compression stroke, may result in a broken connecting rod and a twisted crank shaft.

Two internal bosses are formed on the piston, one of which is shown in section in Fig. 6. These are drilled to take the hollow case-hardened steel gudgeon pin, upon which the small end of the connecting rod swings.

The gudgeon pin has a tendency to rotate and to endwise movement which is overcome in a variety of ways. In one construction the bosses are tapped and

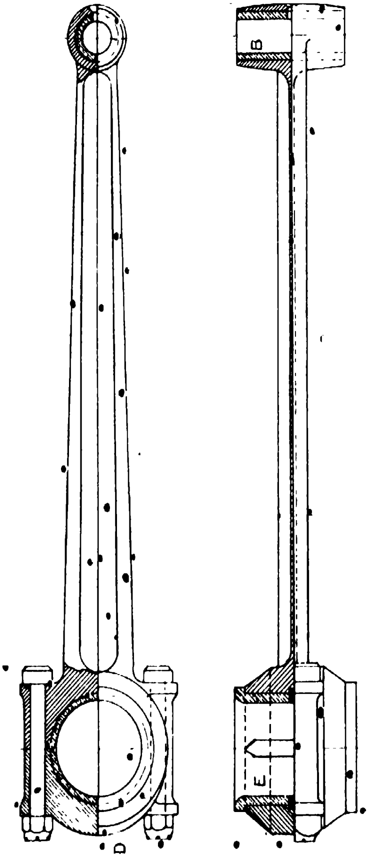


FIG. 7.—Connecting rod

set-screws are used, in another form the pin is tapered and driven into the bosses which have been correspondingly reamered out. A cheap and effective way consists in so placing one of the piston rings that it passes around the ends of the pin. In one other method, a tapered pin is screwed into and expands the split ends of the gudgeon pin.

Connecting Rods.—These are steel stampings of H form in cross-section, as this enables the weight and cost of manufacture to be kept low. The round rods of standard steam-engine practice have the advantage in that they may be drilled with a central longitudinal hole to provide a passage for lubricating oil where forced feed lubricating systems are employed. A very usual form of rod is shown in part sectional plan and elevation in Fig. 7, the small end A having a gun-metal bush B which is pinned to prevent it turning with the gudgeon pin. The big end has a cap D so that it can be coupled to the crank pin, and provision is made for easy adjustment and repair of the brasses E. The brasses are lined with white metal, and in general the remarks made on page 17 in connexion with main bearings hold true for the big end. Constructionally, the length of the connecting rod demands consideration only from the point of view of the height of the completed engine but the effect produced by using different lengths, as considered from the point of view of the mechanics of the problem, is not so simple. In ordinary practice the length of the rod runs to about 2½ times the length of the stroke.

Owing to the disposition of the bearings so that the centres of the gudgeon pin and crank pin are not in the same vertical plane, the connecting rod takes one of the forms shown diagrammatically in Fig. 8,

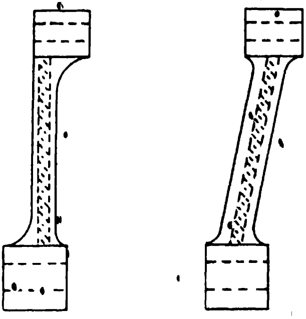


FIG. 8.—Connecting rods not centrally loa

the design being much heavier since the rod is subjected to compound bending forces. An example of the first form occurs in Fig. 11.

Crank Shaft.—For a four-cylinder engine the crank shaft is almost always provided with three

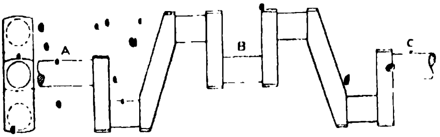


FIG. 9.—Four-throw crank shaft with three journals.

journals as at A, B, C, in Fig. 9, four crank pins being connected to them by webs rectangular in cross-section. The forward end is suitably shaped to take the driving pinion for the cam shaft, and also with means whereby the starting handle can be connected with it. The rear end carries the fly-wheel, which is secured thereto either by a flange and bolts as in Fig. 11 or the end is tapered and a key used.

The shaft is formed from the solid, the journals and the pins being accurately ground to size; the pins and webs may be drilled with holes for the passage of lubricating oil. Chrome vanadium steel in which there is 1 per cent of chromium, 0·2 per cent of vanadium, and 0·25 per cent of carbon, or nickel steel in which there is 3·5 per cent of nickel and 0·3 per cent of carbon, are the steels most commonly used for crank shafts.

With single-throw crank shafts for single cylinders, weights are attached to that part of the web remote from the pin in order to balance the reciprocating parts. Balancing is also employed in two-throw crank shafts, and not infrequently the webs take the form of circular disks.

When designing the main bearings and crank pins the product of the diameter by the length multiplie by 600 should be made equal to the maximum pressure in lbs. the pin or bearing has to take. This product of length by diameter is known as the *projecte area.* The length of a bearing is limited by the overal length of the engine and by the diameter of the shafting necessary to transmit the power, the calculatio being compounded of these two factors. In practic the value for the diameter is equal to 0·8 times th length. The bearing nearest to the fly-wheel is usuall made longer than the others owing to the extra stres put upon it by the varying effort of the fly-wheel The size of the crank shaft can be determined by considering each part as a beam subjected to combine bending and twisting.

When the axis of the shaft is not in the vertical plane containing the centre lines of the cylinders, it is said to be "offset" or "desaxé". The side thrust, during the explosion stroke, of the piston on the cylinder wall is much less in this arrangement than in the ordinary arrangement, which one can prove when doing the exercises at the end of Chapter IV.

Fly-wheels.—The fly-wheel is primarily used to render uniform and steady the rate of revolution of the rotating shaft; it stores up energy during the explosion stroke and yields it up during the other three strokes. The cast-iron rim is connected by arms or an annular disk with the boss or nave; and may form part of or carry the clutch. In some cases suitable vanes thereon act as pumps or fans to draw air through the radiator.

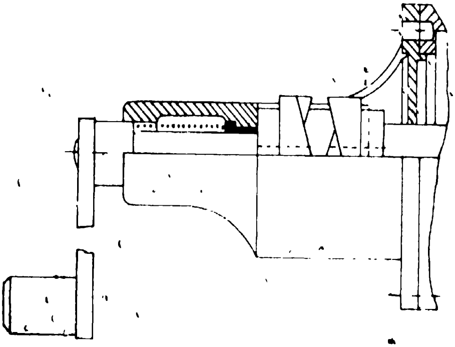


FIG. 10.—Starting handle and supporting bracket.

Starting Handle and Apparatus.—The initial movement of the crank shaft which drives the valve and ignition gearing has to be effected by some external means, and for this purpose a lever with ratchet connexion to the crank shaft is fitted which is adapted to be manually operated. In Fig. 10 a form is shown

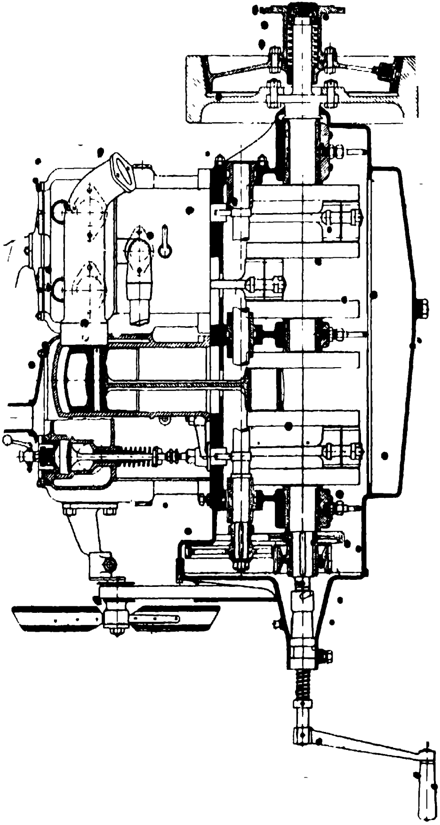


Fig. 11.—Complete cylinder engine.

in which the handle is supported in a bracket bolted to the front of the crank case. Similar inclined surfaces on the handle and crank shaft are normally kept out of engagement by a spring. To start up, the handle is pressed forward until these surfaces engage and then revolved. In Fig. 11 the construction is somewhat different, an inclined slot on the handle co-acting with a pin through the shaft.

Latterly, power plant has been used as a starting apparatus, comprising spring-motors or electromotors coupled to the crank shaft. Compressed air or acetylene, with suitable distributors to the cylinders, is also used, and in this case the power is applied to the pistons.

Complete Engine.—When the various parts just referred to are assembled, the completed engine appears as in the elevation given in Fig. 11. One pair of cylinders is shown in outside elevation with the exhaust and inlet piping in place. A section through the cylinder piston, etc., and through one valve chamber is also given. Some of the features have already been pointed out, and others will be referred to in more detail as the points come up for consideration.

CHAPTER III.

PROPERTIES OF GASES.

THE pressure, volume, and temperature of a given mass of gas are dependent upon each other, the relationship between these properties being expressible mathematically. Suppose a given mass of gas

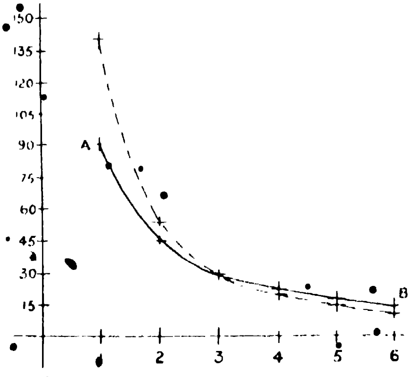


FIG. 12.—Pressure-volume curves for a gas.

to have a constant temperature, then it is known that expansion or contraction of the gas is accompanied by a fall or rise in pressure obeying the law, known as Boyle's Law, P . V = K, where P is the pressure and V is the volume at any one instant.

The full curve, Fig. 12, represents graphically the changes in pressure and volume of a gas obeying this law, the graph being called an Isothermal Curve.

Consider the point A where the pressure equals 90 and the volume equals 1, the product equals 90. It will then be found that at another point, say B, the product will also be 90—actually the pressure is 15 and the volume is 6. Similarly for any other points on the curve.

Suppose that instead of the temperature remaining constant the total quantity of heat in a given mass of gas is constant, then the pressure and volume follow the Adiabatic Law, $P \, . \, V^n = K$ where $n = 1 \cdot 4$. The dotted line shows the connexion between pressure and volume under these conditions for a gas which has a volume 3 when the pressure is 30.

Changes in volume consequent upon changes in temperature, the pressure being constant, follow the law, known as Charles' Law, $V_t = V_o \; (1 + at)$, where V_t is the volume at temperature t^0 and V_0 at temperature 0^0. The coefficient a equals $\frac{1}{461}$ or $\frac{1}{273}$ for the Fahrenheit and Centigrade scales of temperature measurements respectively, hence

$$(1 + at) = (1 + \tfrac{1}{461} \, . \, t) \text{ or } (1 + \tfrac{1}{273} \, . \, t)$$

$$= \left(\frac{461 + t}{461}\right) \text{ or } \left(\frac{273 + t}{273}\right)$$

and the values $273 + t$ or $461 + t = T$ are said to be Absolute Temperatures.

When only the mass of the gas is constant the preceding laws are combined into the form $\frac{P \, . \, V}{T} = K$.

A fairly satisfactory approximation to the actual conditions existing on the explosion and compression strokes is expressed by the equation $P . V^{1.3} = K$, K being a constant.

Above the piston there is always a certain amount of free space, the minimum value of which occurs when the crank is at its inner dead centre. This volume is known as the *clearance* or *compression volume*. When the crank is at its outer dead centre, the space is of maximum value and equals the compression volume plus the volume swept out by the piston.

The ratio $\frac{\text{Maximum Volume}}{\text{Minimum Volume}}$ = the ratio of compression, the value of which is somewhere in the region of 5·00.

In a diagram showing the pressures in the cylinder of an engine working on the four-stroke cycle, OA and OB set off along the OX line of Fig. 13 represent these minimum and maximum volumes just referred to. If AB represents the stroke, as another way of stating the same case, then OA is the stroke equivalent of the compression volume, that is OA is equal to the compression volume divided by the cross-sectional area of the cylinder. At this stage it will be as well to note that the quantity of *work* performed by a machine is measured by the product of the force exerted into the distance through which the force is exerted. If we can obtain the average pressure exerted by the explosion gases upon the piston, then by multiplying this average force by the length of the stroke we get the work performed during the explosion stroke. In a similar manner the work absorbed in compressing the gases can be obtained by finding the average pressure during the compression stroke and multiplying by the length of the stroke. The pressure of the gas in the cylinder during the four strokes of the cycle may be set out on a single

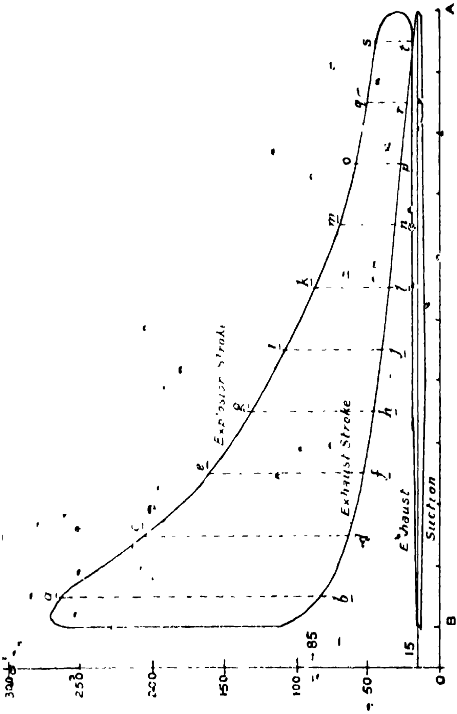


FIG. 13.—Theoretical indicator diagram.

diagram, as in *Fig.* 13, pressures being marked off parallel to the line OY from the base line OA. Such a diagram is known as the *Theoretical Indicator Diagram*, and in the case shown the explosion pressure has been taken as 270 lb. per square inch and the compression at 85 lb. per square inch.

To obtain the *mean effective pressure* divide the diagram into ten vertical divisions of equal width, draw the ten middle ordinates (shown dotted), add together these ordinates, *ab*, *cd*, *ef*, *gh*, *ij*, *kl*, *mn*, *op*, *qr*, *st*, and divide by ten. The value so obtained represents on the proper scale the mean effective pressure. For all practical purposes, the pressures existing on the exhaust and suction strokes may be neglected.

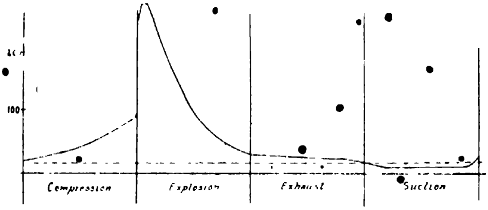


FIG. 14. —Pressure diagram for separate strokes.

Although one diagram will do, yet for the sake of clearness, and also for future use in connexion with torque diagrams, the pressure graph of Fig. 13 may be spread over the four strokes as in Fig. 14. The average pressure for the explosion and compression strokes should then be determined by the method of mid-ordinates as above. When the average compression pressure is subtracted from the average explosion pressure, the mean effective pressure, say P lb., is obtained. The total pressure acting on the piston equals P . A, in which

P is the M.E.P. in lb. per square inch
and A is the projected area of the piston.

The distance through which this force is exerted is equal to the length of stroke L feet.

Hence the work done per cycle = P . A . L foot lbs.
Let E be the number of explosions per minute.
Then the work done per minute = P . A . L . E foot lbs.

The horse-power is therefore $\frac{P.A.L.E}{33000} = H.P.$

If a planimeter is used to obtain the area of the

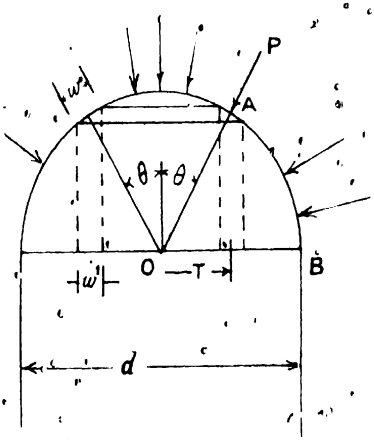


FIG. 15.—Pressure on a domed piston.

diagram (Fig. 13) we get at once the value of the expression P . A . L, care being taken to remember the scales to which the separate factors have been plotted.

Projected Area of the Piston.—It is the area of a circle of diameter equal to that of the cylinder. Suppose the head of the piston is convex and hemispherical, then the pressure is everywhere acting normally or at right angles to the surface as indicated by arrows in the section shown in Fig. 15. The problem before us consists in finding out whether we are justified in saying that the total downward thrust on the piston is P . A, A being $= \frac{\pi d^2}{4}$. Now consider a thin circular strip A of width w subtending an angle 2θ. The horizontal resolutes of the pressure on this strip balance one another, whilst the vertical resolutes P . cos θ acting on an area $2\pi r . w$ total up to P . cos θ . $2\pi r . w$. When projected on the circular section at the base of the head the strip under consideration has a width $w^1 = w . \cos \theta$, and a direct pressure thereon would equal P . $2\pi r . w^1$ = P . $2\pi r . w . \cos \theta$. Now this is the sum of the vertical resolutes of the forces on the strip A just considered. The summation of the whole of the resolutes is therefore equal to P. (The sum of the areas of all such circular strips as the one of width w^1) = P. (area of the circle of radius OB) = P . $\frac{\pi}{4} d^2$ = P . A. Even if the head is irregular, as with pistons used on some two-stroke engines, the same notation holds good.

Instead of theorizing as to the pressures in the cylinder, an indicator may be used which automatically plots the actual pressures.

In the older forms, the diagram is marked on a card placed on a drum which is made to rotate in accordance with the linear movement of the piston At the same time a pointer moves vertically corresponding to a rise or fall of pressure in the cylinder The indicator is screwed into the cylinder whereby the gases can act on a small piston which through linkwork actuates the pointer. Indicators of this kind have not proved very satisfactory for use with petrol engines, and have been replaced by others involving optical principles.

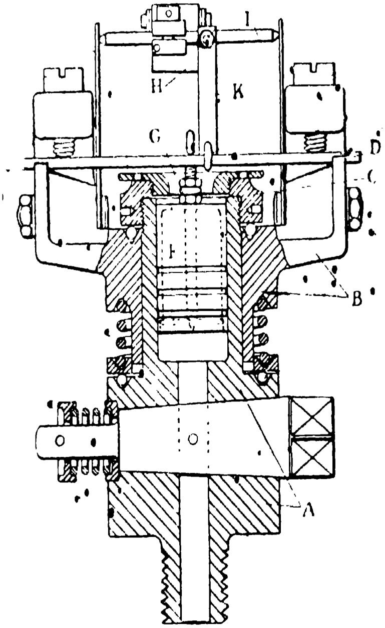


FIG. 16.—Hopkinson indicator.

Such an indicator is the Hopkinson, shown partly in section in Fig. 16. The block A is screwed into the ordinary indicator hole of the engine. A frame B fits over this block, sufficient clearance being left to provide for unequal expansion. It is held up by a spring into engagement with the lower face of a nut C, a ball race being provided. This frame is positively connected by linkage to a reciprocating part of the engine and is thus oscillated about the axis of the block A. The piston F slides in a bore in the block A and at the top is provided with a hook G which rests on a spring D consisting of a flat strip of steel. The mirror H is clamped to a steel spindle I and is moved by the spring D through an intermediate spring K. The mirror is thus turned about the axis of the spindle I by an amount proportional to the pressure in the cylinder. A beam of light falling on the mirror when reflected thus receives the two movements necessary for producing a diagram. When the beam falls on a piece of photographing paper a permanent diagram is obtained.

The M.E.P. obtained from an indicator diagram of this character, when used in the formula $H.P. = \dfrac{P . A . L . E}{33000}$, gives what is called the Indicated Horse-Power, or I.H.P.

CHAPTER IV.

BRAKE HORSE-POWER, DYNAMOMETERS, EMPIRICAL FORMULA FOR HORSE-POWER, AND MECHANICS PROBLEMS.

THE work done in overcoming friction of the moving parts of an engine when subtracted from the I.H.P. gives the useful work which can be obtained from the crank shaft. This work is directly measurable by means of an instrument or piece of apparatus called a dynamometer. As most of these act on the principle of absorbing the output by a brake, the useful power is referred to as the Brake Horse-Power, or briefly the B.H.P.

The fraction $\frac{\text{B.H.P.}}{\text{I.H.P.}} = \eta$ gives a value for the mechanical efficiency of the engine, a value which approximates to 0·85.

Fig. 17 shows a very simple form of brake or absorption dynamometer suitable for use on small-powered engine. For high powers, the method of applying the external braking force requires some modification, and the brake blocks or rim of the pulley to which the brakes are applied are made hollow so that water may be supplied to take up the excess heat that is not radiated by the apparatus itself. Returning to the simple form, it will be observed that the brake blocks are carried by a rope to the ends of which are applied two forces, P lb. and W lb. in the shape of a spring balance and a weight respectively. Suppose the diameter of the pulley to be D feet (if the rope is so thick that its centre is some distance from the rim then the distance D should be measured from A to B), and assume also that the number of revolutions is N per minute.

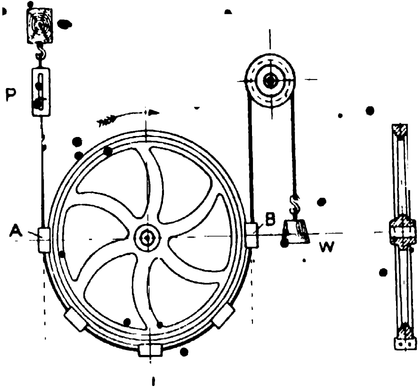


Fig. 17.—Absorption dynamometer.

Then the B.H.P. $= \dfrac{\pi . D . N . (W - P)}{33000}$, since a force (W − P) is overcoming friction, and acts through a distance $\pi . D . N$ feet per minute.

A handy form of Absorption Dynamometer is the Walker Fan type, consisting of two arms adapted to be clamped to the power shaft and to which blades are fixed at predetermined distances from the centre of the shaft. The power is absorbed in overcoming the resistance of the air to the motion of the blades as they are rotated by the shaft. The apparatus is calibrated or marked so that the B.H.P. can be read off at once.

At works testing a large number of engines every week, each engine is coupled to an electric machine the power of which is measured and recorded on a time sheet. By multiplying this power by the efficiency of the machine, say 98 per cent, the power of the engine under test is obtained.

Owing to fluctuations in the position of the recording lever or beam of light, the Torsion Meter now so extensively used on steam engines cannot be applied to internal combustion engines with a reasonable chance of getting an accurate or delicate reading.

Empirical Formulæ.—The horse-power can also be obtained from empirical formulæ based on previous experiments on other engines. The formula adopted by the Royal Automobile Club and the Treasury for taxation purposes is: $H.P. = 0{\cdot}4\ d^2 . N.$ N being the number of cylinders, and d the diameter of the cylinders in inches. This also includes the assumption that the number of revolutions are 1000 per minute, and that the mean effective pressure is 67 lb. per square inch. Although not included in the formula, the stroke should be a factor, especially where modern long-stroke engines are concerned. Lanchester has modified the R.A.C. formula to include stroke, the equation taking the form $H.P. = k . d^{1{\cdot}5} . s^{0{\cdot}5} . N.$ In passing, it should be noted that the equation is of the second order, as all formulæ must be in order to represent H.P. correctly.

Forces Acting on the Piston Due to Acceleration *of the Reciprocating Parts.*—When estimating the weight, w, of the reciprocating parts, half the weight of the connecting rod, which has a part reciprocating and part rotary motion, is added to the weight of the piston and its fittings which have a pure reciprocating motion. To find the value of the acceleration forces, two important laws of mechanics are used.

(1) When a body of weight w is moved with an acceleration f the force required to effect this is

$$P = \frac{w \cdot f}{g}.$$

(2) When a point moves with uniform velocity v feet per second in a circle of radius r feet its radial acceleration is $\frac{v^2}{r}$ feet per second. Now at the two dead points, A, B, on the crank pin circle set out in Fig. 18, the connecting rod may be considered as swinging about the gudgeon pin as centre, so that the crank pin has a momentary movement in two circles. In consequence, and in accordance with Law 2 above, it has an acceleration at A of $\left(\frac{v^2}{r} - \frac{v^2}{l}\right) = \frac{v^2}{r}\left(1 - \frac{1}{n}\right)$, and at B an acceleration of $\left(\frac{v^2}{r} + \frac{v^2}{l}\right) = \frac{v^2}{r}\left(1 + \frac{1}{n}\right)$ where n is the ratio of the

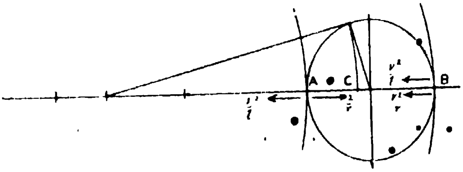


FIG. 18.

length of the connecting rod to the radius of the crank pin circle. At the dead points these accelerations are also the value of the acceleration of the piston. When the connecting rod and crank are at right angles, the piston being a distance AC from its inner centre A, the acceleration is of no value.

If we use Law 1 above to obtain the total pressure and then we divide the pressure by the area of the piston, a stroke-pressure diagram, Fig. 19, can be drawn as follows: At A make AM to represent on a proper scale the acceleration-force

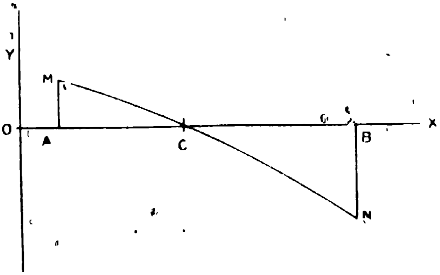


FIG. 19.—Acceleration-force diagram.

$$\frac{w}{g}\cdot\frac{v}{r}\left(1-\frac{1}{n}\right)\div\frac{\pi}{4}\cdot d^2$$

at the inner dead centre, and at B make BN to represent the force $\frac{w}{g}\cdot\frac{v^2}{r}\left(1+\frac{1}{n}\right)\div\frac{\pi}{4}d^2$. Since the forces are oppositely directed BN will have to be below the line AB if AM is above. Let C be the position of the piston when the rod and crank are at right angles. A circular arc through MCN completes the diagram.

Correction of the Indicator Diagram.—Whilst the piston is moving from A to C the acceleration forces are opposing the pressures exerted by the gases, and during the part of the stroke from C to B they act with the gas pressure. If, therefore, the acceleration diagram is superimposed on the indicator diagram the resultant pressure on the piston may be obtained.

We are now in a position to obtain a *Torque or Crank Effort Diagram.* Let the connecting rod NC, Fig. 20, be an angle ϕ to the line of centres NO, P being the pressure on the piston, S the pressure along the rod, and Q the tangential force at the crank pin. Produce the rod to meet OF in T, and with centre N radius NC swing an arc to cut AB in C. Then AC gives the distance of the piston from the end of its stroke, and OT represents Q on the scale that OC represents P.

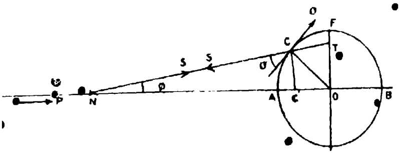


FIG. 20.—Crank effort.

For those mathematically inclined, the proof of the above is as follows: $S \cdot \cos\phi = P$ and $S \cdot \cos\theta = Q$, hence

$$\frac{P}{Q} = \frac{\cos\phi}{\cos\theta} = \frac{\sin CTO}{\sin TCO} = \frac{OC}{OT}$$

Having thus obtained the tangential force Q on the crank pin for any position C of the piston in relation to the resultant pressure P on the piston which is obtainable from the corrected indicator diagram, the torque is obtained by multiplying the

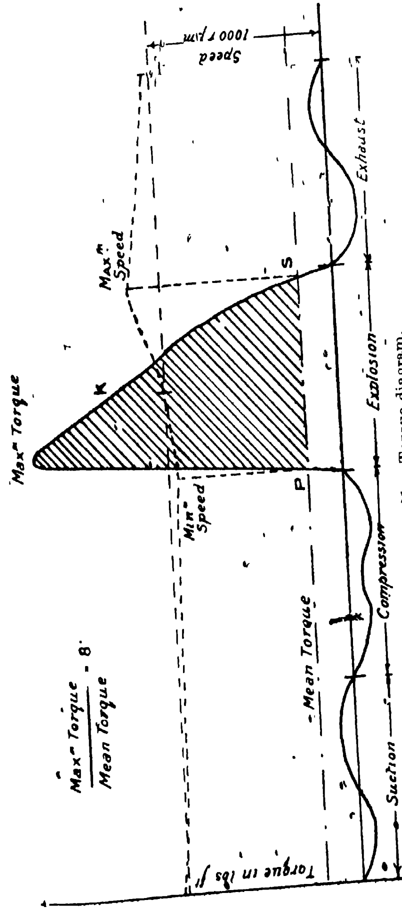


FIG. 21.—Torque diagram.

force Q by the arm OC of the lever, i.e. by a constant.

When the torque is plotted on a "stroke" base the complete diagram for the four strokes for a single cylinder will approximate to that shown in Fig. 21. For two or four or six cylinders a corresponding number of such diagrams are plotted to the same base and a compound curve drawn, due allowance being made for the fact that the explosion strokes are not coincident for the various cylinders.

The mean torque should be obtained by the method of middle ordinates. When plotted it cuts the curve at P and S, the shaded area PKS being the energy stored in the fly-wheel during the explosion. By deduction, P and S are positions of minimum and maximum speeds respectively. The dot and dash line represents the speed curve for the cycle.

Energy Stored in the Fly-wheel. Let M, m, and N be the maximum, minimum and mean revolutions of the fly-wheel per minute. Also assume the moment of inertia of the fly-wheel to be I.

Then $\frac{I}{2g}\left(\frac{2\pi}{60}\right)^2 (M^2 - m^2) = \frac{3}{4}$ of the energy of a cycle = area PKS.

If $\frac{M - m}{N} = k$, a constant known as the Coefficient of Fluctuation of Speed, then the expression $(M^2 - m^2) = (M - m)\ (M + m) = k\,.\,N\ (M + m) = 2\,.\,k\,.\,N^2$.

As a matter of interest if torque is the product of a tangential force by the distance from the axis at which it is acting, then by multiplying the average torque by 2π we get the work done per revolution. If T is the mean torque in lb. feet, then work per revolution equals 2π T foot lb. and B.H.P. = $\frac{2\pi . T . n}{33000}$.

Exercise.—Using the preceding paragraphs as a guide, draw an indicator diagram such as would normally be obtained from a single-cylinder petrol engine working on the four-stroke cycle. Let the compression and maximum pressures be 85 and 270 lb. per square inch respectively. From this determine the crank effort diagram, assuming the diameter of the cylinder to be 4 inches, the stroke 5 inches, and length of connecting rod 10 inches. The weight of the piston and half the weight of the connecting rod equals 5½ lb. Find the ratio of the maximum torque to the mean torque. Show how you would determine the energy it is necessary to store in the fly-wheel when the coefficient of fluctuation of speed is 5 per cent. Use general terms for such data as is necessary but not supplied with specific values above.

As a further exercise the student should obtain the maximum side thrust of the piston on the cylinder walls in the two cases: (1) of an ordinary engine, and (2) with the desaxé arrangement. Similarly the torque should be plotted and compared, the case of a 4-inch × 5-inch engine being used, with and without an offset of ½ inch. Compare also the torque of two 4-inch diameter engines A, B with 5 and 7-inch strokes respectively.

CHAPTER V.

VALVES: CONSTRUCTION, ARRANGEMENT, AND ACTUATION.

THE admission and exhaust of the gases to and from the cylinder of an engine operating on the four-stroke cycle are controlled by valves. Up to quite recently only one kind of valve was used by manufacturers, viz., the poppet or mushroom, but now other types have been taken up after extensive trials and much discussion. For practical purposes five heads are required in classifying the types as follows:—

1. Poppet or mushroom.
2. Sleeve.
3. Rotary piston or plug.
4. Sliding piston.
5. Rotary disk.

Poppet Valves.—These have the form shown in Fig. 22, being constructed of steel, nickel steel, or pure nickel. The conical face is designed to engage a corresponding seating in the cylinder casting, the width of bearing surface being about $\frac{3}{32}$ inch. The exhaust valve is subjected to very high temperatures, which may result in warping and in loss of efficiency. In this case also the head may become corroded and appears to be eaten away, a trouble known as "pitting". With the better steels now employed this does not occur so quickly. At one time cast-iron heads fixed on steel stems had a slight vogue, as it was found cast iron was better than steel in respect to corrosion. The lower part of the stem is case-hardened. At the bottom of the stem A, a slot is made through which passes a cotter B, adapted to hold a collar C. The lower end of the valve spring rests on this collar whilst the upper end takes against the cylinder casting. These springs which tend to keep the valve on its seat are arranged to exert a pressure of about 50 lb. when at full length and 80 lb. when compressed. The ease with which the gases may pass the valves when open depends on the diameter and the lift. In the case of the exhaust valve it is found that the greater the diameter the greater the liability to warping; whereas if the available passage is obtained by increasing the lift then an increased chattering and noise results. It is customary to make the lift equal to one-fifth of the diameter, and to make the diameter of the stem equal to one-quarter of the smallest diameter of the valve seat.

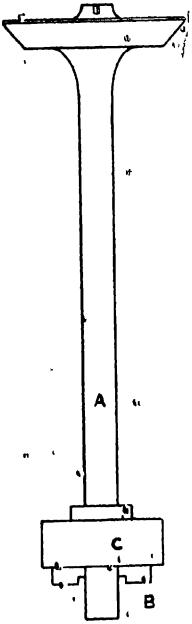


FIG. 22.—Poppet valve.

Arrangement.—Six possible arrangements of the

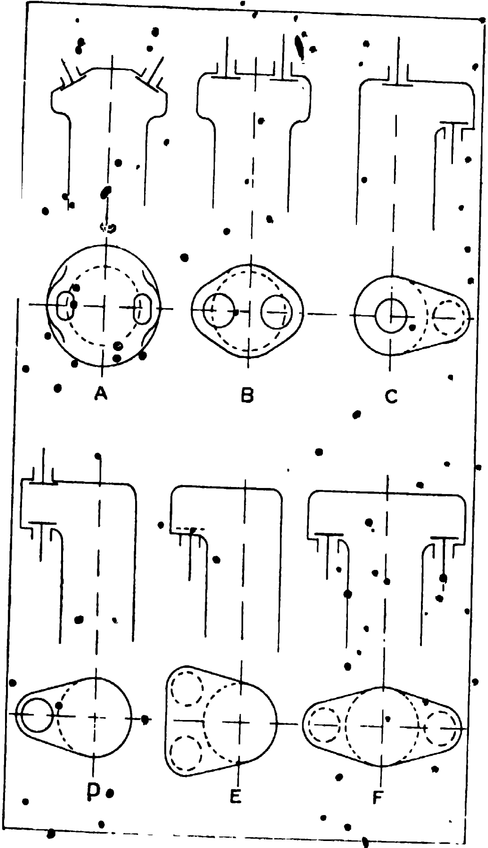


Fig. 23.

valves on the cylinder are shown at A, B, C, D, E, F, in Fig. 23, the particular one adopted in a given case being a compromise among the following features: (1) The number of joints to be made. (2) The faculties for grinding the seatings. (3) The best possible combustion. (4) Ease in clearing the exhaust. (5) The arrangement of gas and water piping. (6) The position of the sparking plug. (7) The overall length of the cylinder. (8) The use of two or one camshafts. (9) Whether rockers or direct tappets are employed. (10) The required compression. The arrangement shown at E is the most extensively used, the cylinder being said to have a T-head. For commercial vehicles, the T-head, shown at F, is much used.

When the camshaft is or camshafts are situated alongside the base of cylinder, the valves are actuated by cams and tappets, or by overhead tappets and rocker arms; and when the shaft is carried on top of the cylinder, the cams act direct or through rocker arms.

The cams may be formed integral with the shaft which is the more usual construction, or made separately; and in this case the cams are keyed to shafts of circular cross-section, or machined to slide on shafts which are squared or fluted. When the integral form is not used, it is possible to provide for an end-wise movement of the cam which is so constructed that it gives a variable lift to the valve.

Cams.—The valves are approximately open during one-half of an engine revolution (180°) and closed during three-halves (540°), and since the camshaft is driven at half the speed of the main shaft it follows that the cam has to act on the valve to open it over a period of one-quarter of a camshaft revolution, that is approximately 90°.

The angles referred to in the following paragraphs are main crank angles. A fairly average setting for the inlet valve is obtained by opening it about 10° late, that is after the piston has passed the inner dead centre and is moving down on its suction stroke, and closing it 20° late. For the exhaust, the opening occurs 40° early, that is whilst the latter part of the explosion stroke is being performed and the closing about 10° late. From the time the exhaust valve begins to open until it closes the main crankshaft goes through an angle of 40° + 180° + 10° = 230°, so that the camshaft moves through an angle of 115°.

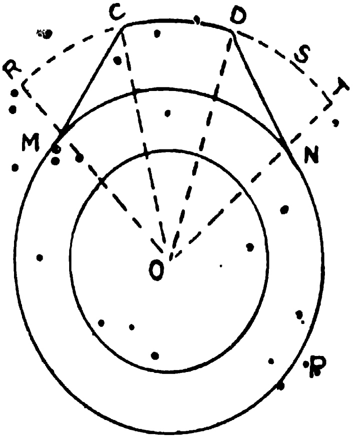


FIG. 24.—Method of setting out cams.

One method of setting out a cam consists in describing a circle MNP with centre O to represent the root circle of the cam. Draw radii MO, NO so that the angle MON = 115°. An arc RST is then drawn with centre O and radius OR equal to OM plus an amount RM equal to the maximum lift of the valve as in Fig. 24. Since the valve cannot be lifted and lowered instantaneously, the root circle must pass gradually into the outer circle in the

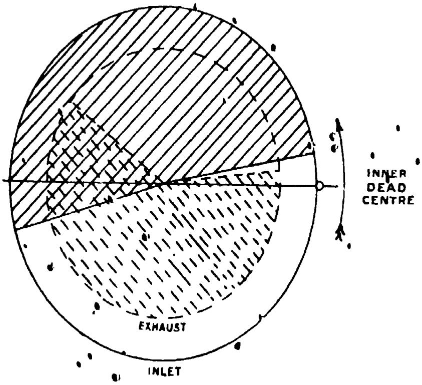


Fig. 25.—Diagram of valve settings.

manner shown, from which it will be noticed that the valve is now open to its maximum extent over an angle COD.

A graphic representation of the valve settings with reference to the crank shaft can be given as in Fig. 25, in which the outer full crank-pin circle is cross-hatched to represent the opening of the inlet valve and the inner dotted circle to represent the opening of the exhaust valve. The direction of motion of the crank pin is represented by an arrow.

Some manufacturers give the openings with reference to the distance the piston has travelled from its extreme positions, in which case the diagram is as shown in Fig. 26.

Although there is considerable difference in the times of opening and closing valves on different engines, the main consideration for the designers is to get as large a charge into the cylinder and to get as much of the exhaust gases out from the cylinder during each cycle as possible. When the piston is at the bottom or top of its stroke it is moving very

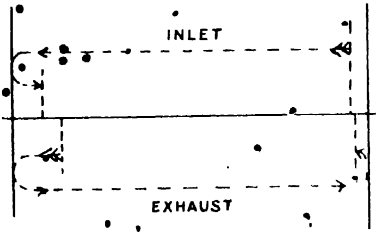


FIG. 26.—Diagram of valve settings.

slowly. Bearing this in mind we can understand why the inlet valve, for example, is closed late. On the down stroke the gases are drawn into the cylinder and acquire a momentum which allows them to flow into the cylinder even when the piston has begun its return stroke, there is therefore a greater charge than if the inlet valve had been shut at the dead centre. The ratio of compression is somewhat altered in consequence, but the final compression pressure is not appreciably altered because of the greater charge.

Again, the early opening of the exhaust does not result in loss of power, as an examination of the theoretical torque diagram for the last part of the pressure stroke will show, whilst the higher pressure in the cylinder at the moment when the valve is opened and the longer time during which it is open lead to a more complete clearance of the exhaust and cooling of the cylinder.

A slight alteration of the cams on well-known engines has been known to increase the mileage per gallon by as much as 50 per cent, the inefficiency in these cases being due to using timings, which, although excellent in practice for another engine, are not suitable for the engine with a different mean speed.

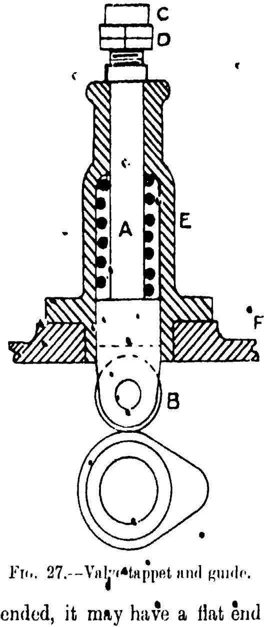


FIG. 27.—Valve tappet and guide.

Another point to remember is that in no case does the cam act directly on the valve stem, an intermediate tappet being used. The tappet may carry a roller, it may be spherical ended, it may have a flat end or a second member is sometimes interposed between the cam and tappet.

These different shapes of contacting surfaces all demand different cam surfaces for corresponding valve movements.

A construction is given in Fig. 27 where the tappet A carries a roller B. The upper part can be adjusted as regards length by the two nuts C, D, the part C which contacts with the valve stem being case-hardened. The guide E is held in the crank case F by dogs and is hollowed to receive a weak spring which tends to keep the roller on the cam. A fibre pad is sometimes let into the part C with the idea of minimizing noise.

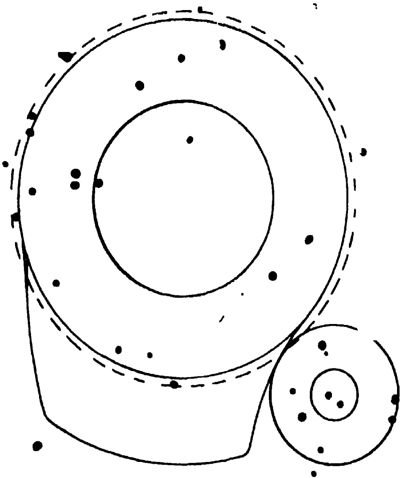


Fig. 28.—Inlet cam for fast-running engine.

The form of cam which gives good service for a fast-running engine is shown in Fig. 28. The dotted circle represents the virtual base circle of the cam, for there is always some clearance between the tappet and valve stem, and consequently some lost motion. With such a cam the velocity of the inlet gases would be approximately constant.

Since the angular velocity of the crank can be taken as constant in a four-cylinder engine by plotting the valve openings against the crank angles as in Fig. 29, the quantity of charge will be proportional to the area of the figure—the velocity of the gases being assumed constant.

In the case of variable gas velocity, the estimation of the velocity at a given instant is determined by multiplying the piston speed at that instant by the cross-sectional area of the cylinder and dividing by the area of valve opening.

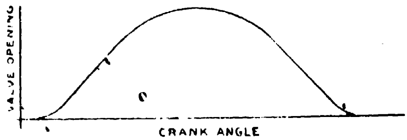


FIG. 29.

The cam shaft is driven off the main shaft by gear wheels, spur or helical, or by silent chain and sprocket gearing. In both cases, the timing can be upset by getting the wheels or sprocket out of their correct relationship, and attention to this point is very necessary when assembling.

The timing is usually marked on the fly-wheel and denotes the setting of the valves of the first cylinder.

As the valve seatings and cam surfaces wear, the former should be trued up with a cutting tool set in a holder like a hand drill, whilst the latter should be carefully ground back to the correct shape.

CHAPTER VI.

VALVES: SLEEVE, ROTARY PLUG, PISTON, ROTARY DISK, MAIN PISTON ACTING AS A VALVE.

In the days when poppet valves were the only form in use, they were generally noisy in action, consequently as more silent engines were demanded, alternative kinds, as well as improvements on the existing kind, were thought out by designers. The main difficulties to be contended with in the new types were those of lubrication and uneven expansion with its lack of gas tightness; and it will be seen that in most forms attention has been directed to proper water cooling, to isolating the valve from the direct action of the first part of the explosion, and to the keeping of the relative speed of the rubbing surfaces as low as possible.

Sleeve Valves.—The pioneer of this type is the Knight, which was made commercially successful by its adoption by the Daimler Company. Two sleeves, A, B, with ports therein are employed. The piston reciprocates in the inner sleeve, and the outer sleeve moves in contact with the cylinder wall C, as indicated in Fig. 30. The cylinder has a detachable head H, and inlet and exhaust ports E and F respectively. The ports *e*, *l*, in the sleeve B, are at the same level, whilst the ports *d*, *d*, in the sleeve A, are at different levels. By putting the cranks from which the sleeves are operated at an angle of about 70°, the ports *e*, *l*, *d*, *l*, can be made to register with each other and with the cylinder ports E, F, so as to provide for the proper control of the working fluid. Grooves are formed on the sleeves for lubrication purposes. As usually designed the travel of the sleeves is about $\frac{1}{12}$ of the piston stroke; the width of the ports is equal to ½ the travel, the thickness of the sleeves 3 to 4 mm., and the compression pressure is about 80 lb.

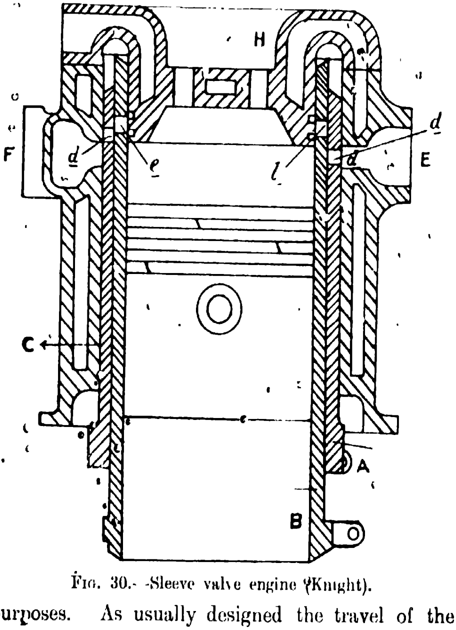


FIG. 30.—Sleeve valve engine (Knight).

In the Argyll engine a single sleeve is used which forms a close-fitting liner to the cylinder. A crank A, Fig. 31, pinned to a lug at the bottom of the sleeve and at right angles to its axis is driven by a rotating spur wheel B which moves the sleeve in such a manner that any point on it has an elliptical motion once every two revolutions of the main crank shaft. The wheel B rotates in a casing C which is bolted to the upper half of the crank case D. The crank pin A slides in and out of its socket and is utilized to pump lubricating oil to the ad-

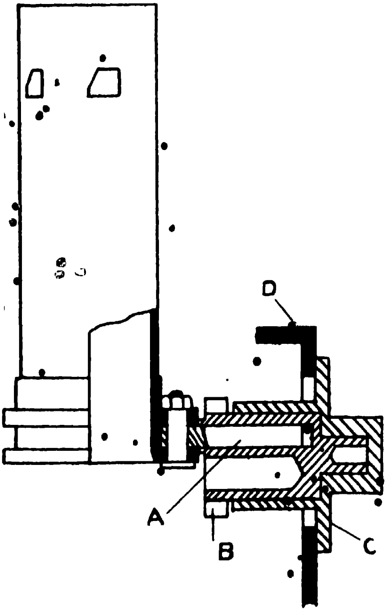


FIG. 31.—Sleeve valve engine (Perrot).

jacent parts. The cylinder has six ports cut in the wall of its combustion chamber, of which three communicate with the induction pipe and three with the exhaust pipe. The sleeve itself has five ports, one acting in common with the induction and exhaust ports. The shape of the ports in the sleeve is shown in Fig. 31, those in the cylinder being of the same shape but inverted.

On a down stroke of the sleeve the exhaust ports are uncovered, and while the sleeve is rotating at the bottom of its travel the inlet ports are opened and remain so until the upper dead centre. At this position all the ports are closed and the ports in the sleeve are housed between the detachable head of the cylinder and extensions of the cylinder walls away from the effect of the explosion.

With all valve systems as already referred to in Chapter V, the time during which the valve ports are opened as well as their maximum area of valve opening has to be taken into account in gauging the effectiveness of the system. Looked at from this point of view, the Argyll system appears to be good, since the valve ports not only reach their maximum opening quickly but remain full open a correspondingly longer time. The sleeve itself has helical grooves which act as lubricating channels.

Rotary Plug.—Of the rotary plug type of valve it is proposed to deal with two kinds, those rotating on a horizontal axis and those rotating on a vertical axis.

The Darracq valve rotates on a horizontal axis in a casting on one side and near the top of the cylinder casting. This casting has a number of ports communicating with the induction pipe, the combustion chambers and the exhaust pipe. The valve has four D-shaped sections one for each cylinder, in fact it is very like a Corliss valve. As shown in the sectional view in Fig. 32, the flat portion does not couple any of the three ports, but a small movement either way would couple the combustion chamber with the inlet or exhaust pipe. Although the arrangement is such that the piston at the upper extremity of the stroke covers the port in the cylinder and so protects the

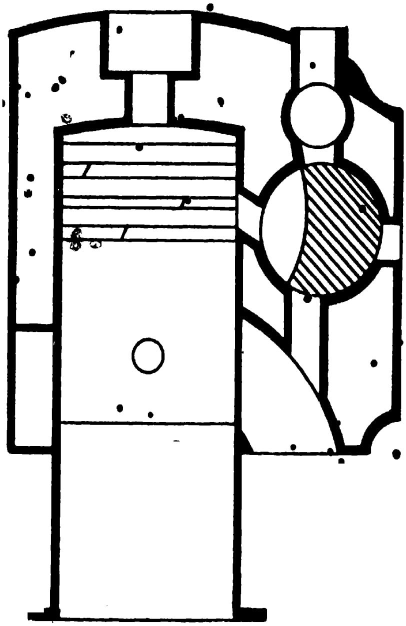


FIG. 32.—Rotary plug valve (Darracq).

valve from the force and heat of the explosion, yet in consequence of this construction the valve timing is not good.

The Itala rotary valve has a vertical axis and

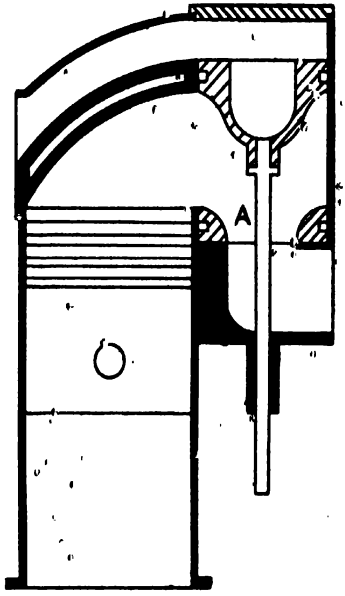


FIG. 33.—Rotary plug valve (Itala).

rotates in a cylindrical casting common to a pair of cylinders.

Ports in the valve A, Fig. 33, and in the two cylinders are adapted to register at the correct times for working on the four-stroke principle. Difficulties as to distortion due to irregular heating are overcome by water cooling the valve itself, the water entering and leaving the valve through two concentric passages which rotate in glands directly over the valve. The valve rings with which the valve is provided are ixed to the valve casing itself.

Piston Valves.—Of piston valves proper those used on the Hewitt engine are the best known. Although

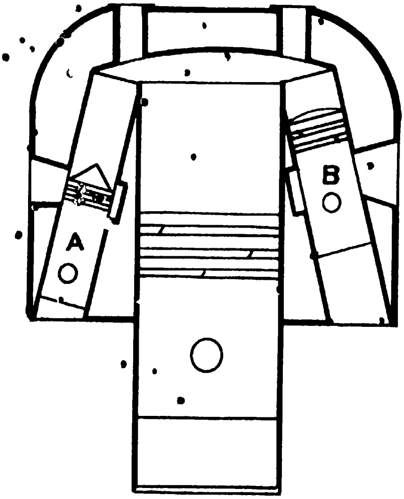


FIG. 34.—Hewitt piston valve.

shown with inlet valve A and exhaust valve B on either side in Fig. 34, they can be arranged on one side and driven by connecting rods off a common valve-crank shaft. Both valves reciprocate in cylindrical castings which are ported and communicate with the inlet and exhaust pipes. In this engine, practically any desired valve setting can be obtained.

Disk Valves.—There are no engines with efficient disk valves. Either there is too great an area exposed to the explosion, or if part of the disk is masked there is uneven expansion. A considerable amount of power also is required to drive them, so that the mechanical efficiency is rather low.

Valveless Engines.—Those engines in which the main pistons act as valves remain to be dealt with. These can be more accurately described as valveless engines than those having valves of the types already described in this chapter. A practice has arisen among manufacturers of labelling all engines not employing poppet valves as valveless: this point should be noted by the student in his general reading in order to avoid confusion. As a class, it will be found that valveless engines operate on the two-stroke cycle referred to on page 7.

In its elementary form, the cycle works out as follows: The mixture is drawn into the crank case on the upward stroke of the piston, and on the downward stroke the mixture is compressed therein. In the cylinder itself and during the first part of the downward stroke, the firing and expansion of the gases takes place; toward the end of the stroke the piston uncovers the exhaust port and immediately after the inlet port. The fresh charge flows from the crank case and upon entering the cylinder is directed by a deflecting projection on the piston to the top of the cylinder away from the exhausting gases which it thus assists to expel. Upon the upward stroke and after both ports are covered, the charge is compressed. At the end of the stroke the cycle commences over again.

The only British car to which a two-stroke engine is fitted is the Valveless made by Messrs David Brown of Huddersfield. The engine is of the U or Siphon type, with two cylinders as shown in Fig. 35. The exhaust ports are placed in the walls of one cylinder A, the inlet ports in the other cylinder B, and a common combustion space C connects the two. Instead of a projection on the piston the dividing wall W serves to separate the incoming charge from the exhaust. It will be observed that the exhaust from the cylinder B moves in the same direction as the new charge, there is therefore less possibility of the two sets of gases mixing, with its resultant loss of unburnt gas in the exhaust and diluted mixture in the cylinder, than is the case with the single cylinder type wherein the exhaust

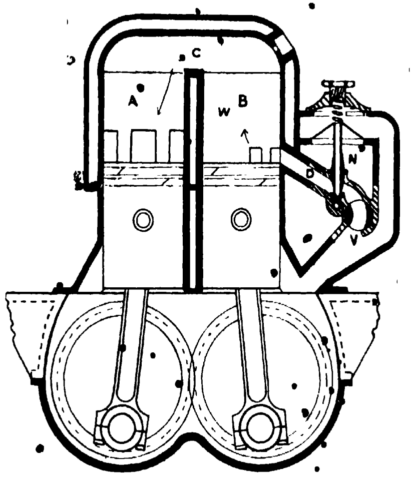


Fig. 35.—Valveless engine (two-stroke).

and new mixture have opposite directions of flow. The possibility of explosion in the crank case is also avoided by drawing air only into it and letting the petrol mix with the air in the induction passage D.

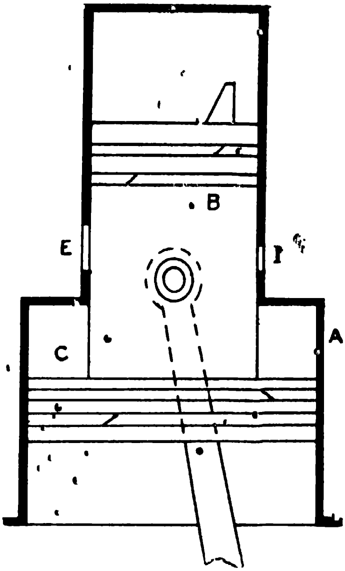


FIG. 36.—Two-stroke engine with differential piston.

A rotary valve V controls the air, and a needle valve N the petrol.

The two connecting rods are attached at their big ends to two oppositely revolving disks on the rims of which are teeth which are in engagement. The shafts of both disks carry fly-wheels, so that the torque is very evenly transmitted.

The form which finds most favour in France is shown diagrammatically in Fig. 36. The cylinder is enlarged as at A and a two-diameter or differential piston B is adapted to work therein. The upper part of the piston acts in the ordinary manner to uncover the inlet and exhaust ports I, E, respectively, whilst the annular part of the lower portion draws the charge into the space C on the down stroke, and on the up stroke forces it to the port I of an adjacent cylinder. The space C thus takes the place of the crank case in other constructions. The suction and preliminary compression of the charge is not dependent on the condition of the main bearings, and in this particular there is a marked advantage over the type employing the crank case. In going into the relative torque and efficiency of two- and four-stroke engines it must be remembered that a direct comparison is not at present really possible, since so little attention has been given to the former, but the performances of the few cars having the two-stroke engines certainly compare favourably with other cars.

CHAPTER VII.

FUELS AND CARBURETTERS.

ALL forms of energy are interconvertible; it is the function of the engine of a motor car to obtain or produce heat energy and convert it into mechanical energy. Actually an oil or a spirit is used by the engine, and burnt therein with air to produce the heat energy.

Paraffin is the lightest of the oils, and petrol, benzol, benzine and alcohols are examples of spirits. In the matter of the convertibility of energy one heat unit (British Thermal Units, B.T.U.) is equal to 774 ft. lb. of work. To convert heat units into its equivalent value in ft. lb. it is therefore necessary to multiply by the value 774, which is usually denoted by the symbol J. If 1 lb. of a fuel is completely burnt and x B.T. Units of heat are evolved in the process, then "x" is said to be the *Calorific Value* of the fuel. Approximate values for alcohol, petrol and paraffin are 12, 19, and 23 respectively. When the fuel is not completely burnt the heat evolved is much less, so that it is desirable to test for complete combustion when experimenting or tuning up.

This involves a knowledge of chemistry. All substances are either simple substances, known as elements, or mixtures or combinations of the elements.

Among simple elements are carbon, hydrogen, oxygen, and iron, and these are generally denoted by their symbols, C, H, O and Fe, which represent unit volumes and also stand for the relative weights of equal volumes, these latter being 12, 1, 16 and 56 respectively. For example, if we wish to represent one volume of oxygen in combination with one volume of hydrogen, we use the symbol OH and know that it also stands for a weight of oxygen, 16, combined with a weight of hydrogen, 1 unit. A symbol such as Fe_3O_4 represents a compound in which three volumes of iron is combined with four volumes of oxygen; and the relative weights are:—

$$Fe : O = 3 \times (56) : 4 \times (16) = 3{\cdot}375 : 1.$$

Petrol is a spirit made up of various compounds of carbon and hydrogen belonging to a group with symbol C_nH_{2n+2}, the predominant compounds being hexane (C_6H_{14}) and heptane (C_7H_{16}).

An equation is given below which represents on the left- and right-hand sides respectively the condition of affairs before and after perfect combustion of hexane with oxygen.

$$2 \text{ vols. } (C_6H_{14}) + 19 \text{ vols. } (O_2) = 12 \text{ vols. } (CO_2) + 14 \text{ vols. } (H_2O).$$

The products are carbon dioxide and water.

Now 1 volume of oxygen is contained in 4½ volumes of air, the other constituent of the mixture being nitrogen (N), so that when air is used 4½ × 19 = 85 volumes are required, and the 3½ × 19 volumes of N will be found free in the exhaust, and appears on both sides of the equation. It will be noticed that the proportion of hexane or petrol to air is as 2 : 85 approximately.

When imperfect combustion occurs, as with an over-rich mixture, the exhaust gases represented in the right-hand side of the equation will include carbon monoxide (CO), methane (CH_4) or free carbon (C). Free oxygen (O) is present in the exhaust when the mixture is "weak," since there is not enough carbon to combine with all the oxygen in the air which enters the cylinder.

Paraffin approximates to decane ($C_{10}H_{22}$), and the equation in this case is as follows :—

$$2 . C_{10}H_{22} + 31 . O_2 = 20 . CO_2 + 22 . H_2O,$$

so that the proportion of decane to air is as 2 : 31 × 4½ or 1 : 70.

Commercial benzol is about 90 per cent toluol, the formula for the latter being $C_7 . H_8$. The proportion of air, determined as above, will be seen to be different from that for both petrol and paraffin. In consequence of this a carburetter which is suitable for use with one of these fuels may not act with one of the others without extensive adjustments and alterations.

The proportion of air required and the calorific value of a fuel are not the only properties to be considered in respect to its suitability for use in an internal combustion engine. The density, boiling point, range of distillation, flash point, as also the corrosive effect on the working parts, the safe limits of compression, and safety in handling, all demand attention. When an oil or spirit is heated up, a temperature is reached at which the lighter vapours distil off and at successively higher temperatures the heavier vapours are given off. When the range is low, as with petrol, which is from 80° to 100° C., complete combustion can be more readily effected than with a spirit which commences to distil at 50° C. and continues up to 150°. Below a point or temperature known as the "Flash Point" no combustible vapours emanate from the oil or spirit, so that the application of a naked light is not attended by combustion. At and above this point combustion would result, consequently the higher the flash point the greater the safety.

When a gas is compressed the temperature rises, and the temperature may be such that if the gas is a mixture of a combustible spirit and air, self-ignition takes place, and in an engine could take place before the spark is produced at the sparking plug. This pre-ignition occurs at different compression pressures for different fuels, and in order that it shall not occur under working conditions the highest designed compression for a petrol engine is about 95 lb. and for an alcohol engine should be about 210 lb.

In the approximate equation for petrol, the ratio of petrol to air was 1 : 42·5. Now, with a weak mixture of say 1 : 43 up to a rich mixture of 1 : 42 and between these, combustion can be effected in an engine, whereas none takes place outside these proportions, that is the engine "misfires". The variation of 1 volume of air (43-42) compared with a mean volume of 42·5 (expressed as a percentage it is 2·4) is small and calls for very delicate design of the carburetter or other apparatus supplying the mixture. A spirit in which the air range is 5 per cent would be much easier to deal with.

Carburetters.—In the preceding paragraphs it has been ascertained that the vaporized matter required a definite supply of air for its complete combustion. It is the function of a carburetter to supply to the engine, under all conditions, this correct proportion of air and gas. It has further to produce vaporization. In designing a carburetter to possess this function, the various properties of the fuel must be considered, and in addition it must be borne in mind that the engine of a motor vehicle works under constantly varying loads due to the nature of the road surface, gradient, speed of the car, weight, and so on. The reason for noting these factors is that the engine, as will be seen later, draws in from the carburetter a mixture the quality of which varies with the speed, the load, etc., and this variation should be in accordance with the requirements of the engine.

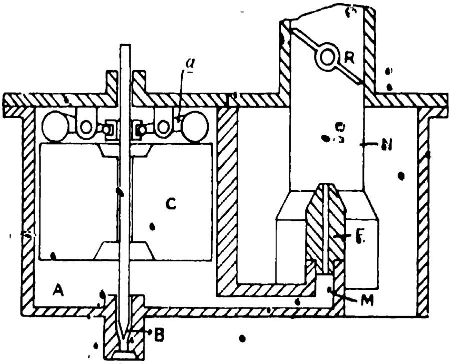


FIG. 37.—Simple carburetter.

Carburetters in general are possessed of two main parts, one being the constant level reservoir or float chamber and the other the mixing chamber. In its elementary form the float chamber A, illustrated in Fig. 37, is supplied with fuel from a tank, either by gravity or under pressure, past the needle valve B. A collar on the valve spindle contacts with two levers *a*, which in turn are moved by the sealed brass drum or float C. When the liquid reaches a pre-determined height the float rises, and through the medium of the levers *a* positively moves the needle valve down on to its seat to cut off the supply. The reservoir A is in open communication with an upturned pipe M, into which is screwed a nipple E having a very small hole bored therein. Surrounding the nipple is a funnel-shaped member N, usually of copper, known as the choke-tube, the adjustment of the conical portion of which relative to the nipple determines the available annular area for the passage of air. The tube is so positioned that the cross-section of minimum value is at the level of the top of the nipple as the induced air then moves with its maximum velocity at this position and more thoroughly mixes with and vaporizes the fuel. Between this tube and the induction pipe of the engine to which it is attached by a flange connexion or union nut, is the throttle valve R which determines the volume of mixture admitted to the cylinders, and which is operated by levers by the driver.

In considering the action of the carburetter, first suppose the throttle valve to be closed, and that the level of petrol in the nipple E is at the top. The pressure of air in the choke-tube will then be equal to that of the atmosphere with which it is in free communication.

Now assume the engine to be turned, either by hand or under power, and that the valve R is gradually opened, air will be drawn from the induction pipe and choke-tube on the suction stroke, so producing a fall of pressure around the jet, with the result that petrol and air is also drawn in. Above the petrol in the float-chamber the pressure is always atmospheric. The higher the speed of the engine, the lower the pressure in the neighbourhood of the nipple, and it is found that the proportion of petrol to air is greater.

The tendency should be the other way, as at the higher speeds the mixture can be slightly weaker. In order, therefore, to obtain the correct proportion the simple form of construction just described has to be modified, the modifications consisting in:—

1. The provision of valved extra-air inlets.
2. The use of multiple jets.
3. The provision of means for varying the area of the jet orifice.
4. The provision of means for altering the height of the choke-tube.

The extra-air inlets are placed in the induction pipes either between the engine and the throttle or between the throttle and the main air. In the former case by closing the throttle when the car is going down hill, and opening the extra air inlets, air only is supplied to the cylinders for braking, with the result that the engine is cooled and the petrol is saved. In the latter case, the valve may be hand controlled or automatically controlled in accordance with the suction of the engine or in accordance with the speed. A carburetter in which the suction effects the control is shown in Fig. 38, the under side of the piston A being in direct communication with the induction pipe B. This piston has a number of ports C which can co-act with ports D in the wall of the carburetter to allow air to pass to the pipe B. A light spring E of adjustable tension is fitted which tends to keep the valve in its upper and closed position.

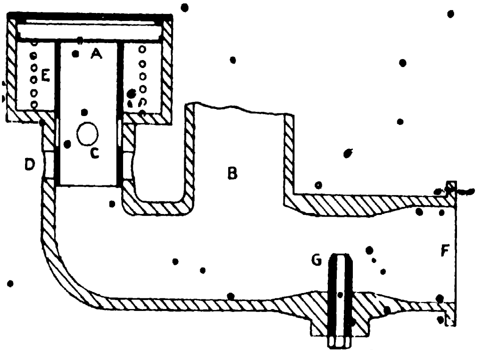


Fig. 38.—Carburetter with automatic extra-air inlet.

The main supply of air enters at F and the choke-tube is formed by the interior walls of the carburetter. At low speeds, the suction is small and unable to overcome the spring E, so that the ports remain closed and a rich mixture is obtained. As the speed of the engine rises, the suction increases and the valve moves down against the spring, so that the ports C, D gradually register with each other and air is drawn in to dilute the rich mixture passing into the choke-tube from the direction of the jet G.

In the second class are constructions which are nothing more than two or more plain carburetters in one casing, a small jet with its own choke-tube which provides a rich mixture being used for starting and slow running, and the other jets, which give weaker mixtures, being brought into use in addition to or in place of the first jet for higher speeds and loads.

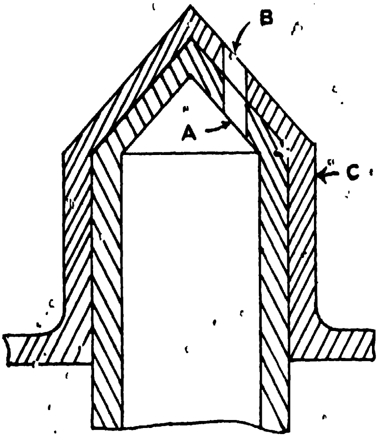


FIG. 39.—Jet with variable orifice.

There are forms in which the jets have a common choke-tube, the jets being opened up successively, as is also the air inlet.

The best known instance of a jet with a variable orifice is that used in the White & Poppe carburetter. The upper part of the jet tube is conical and is bored eccentrically as at A. A similarly bored cap C, Fig. 39, rests thereon. This cap forms part of a casting which acts as a throttle valve and ir inlet control. Any movement of the throttle ever, therefore, results in a movement of the cap. When the throttle is closed, the holes A and B are ut of register and the effective area of the jet orifice s nil, but as the throttle is opened so the holes A nd B get into alignment and the effective area in- reases in the proper proportions. In another form, the variation in the jet orifice is obtained by using a tapered needle valve A, Fig. 40, which projects into the jet B. This valve is attached to a bellows or float C the interior of which is connected by a passage D with the induction pipe E. The varying suction of the engine on the bellows consequently moves the needle A in and out of the jet B and alters the effective area. By properly calibrating the valve, that is, by experimenting and obtaining values for

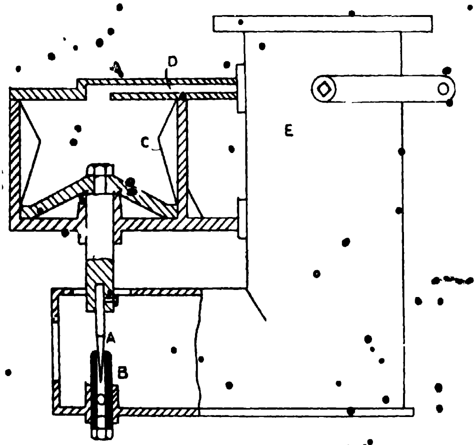


Fig. 40.—S.U. carburetter (modified).

different diameters as at AA, BB, CC, Fig. 41, the correct quantity of petrol can pass from the jet at all speeds.

In the actual carburetter, the jet and axis of the bellows are inclined at 45°, the claimed advantage of which is that variation in the height of the liquid level in the jet does not affect the proper working. The author saw some experiments with one of these S.U. carburetters which without adjustment gave equally good results on petrol, paraffin and benzol. Between each trial the float chamber was emptied and the connexions with the fuels changed over. A dynamometer and a tachemometer, both of the direct-reading type, were used to give comparative results.

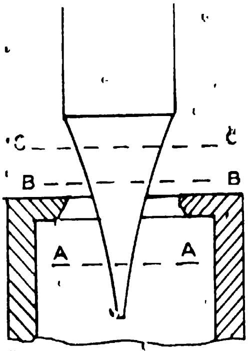


Fig. 41.—Calibrated needle for jet of carburetter.

The inverse of the last-mentioned modification consists in making the choke-tube adjustable, in which case the annular opening or air passage immediately surrounding the jet can be altered. As the jet is of constant size a ready means of altering the richness of the mixture is obtained.

The mixing chamber is sometimes enclosed in a jacket through which is by-passed warm water from the cooling system or hot gases from the exhaust pipe, the object being to warm up the mixture and assist in the vaporizing of the fuel. With the same object in view, the air intake has on some engines been placed in close proximity to the exhaust pipe.

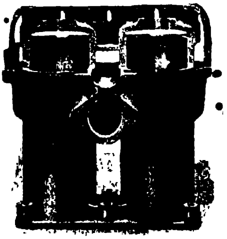


Fig. 42.—Induction pipe integral with cylinder casting.

In those engines with the valves on one side the practice has arisen of fitting the carburetter on the opposite side and casting the induction pipe integral with the cylinder casting in the manner illustrated in Fig. 42, so that it passes through the water jacket, between the pairs of cylinders; in this way condensation of the petrol vapour is avoided. The cylinders are off a White and Poppe engine.

A not unimportant feature in the smooth running of a multiple cylinder is the method of arranging the induction pipes so that each cylinder is equally fed with fuel. As far as possible the length of the path

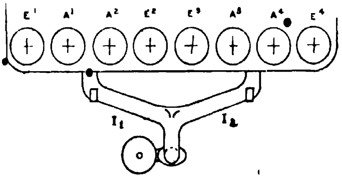


Fig. 43.—Arrangement of induction pipes.

to each cylinder should be the same, an example of this is shown in Fig. 43, the branch I_1 of the induction pipe leading to the valve chamber common to the inlet valves A_1, A_2 of the first two cylinders and the other branch I_1 to the valves A_3, A_4 of the other two cylinders. A bad arrangement for a similar engine is shown in Fig. 44. A disturbing factor, the value of which cannot be readily determined, arises from the existence of periodic wave motions in the induction pipes. These motions have the effect of starving one or two cylinders, but the magnitude is not very great except at certain critical speeds of

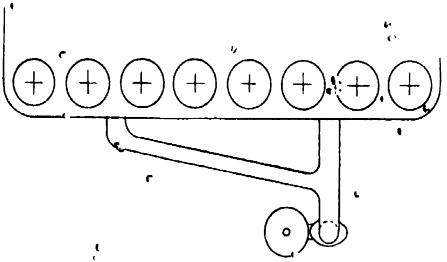


FIG. 44.—A faulty arrangement of induction piping.

and loads on the engine. To prevent these surgings and maintain an even suction in the induction pipe, spiral obstructions and chambers similar to the air chambers of water pumps have been tried.

When the petrol flows by gravity from the tank to the float chamber care must be taken as to the height of the tank relative to that of the carburetter on the chassis, as one has to remember that when the car is going up hill there is a tendency for the supply of petrol to be cut off, owing to the new relative position. For the same reason the float chamber and the mixing chamber should be set crosswise on the chassis as there is then no liability to flooding or starving the jet when the car is not on the level.

If space under the bonnet is a consideration and the float chamber has to be placed in front of or behind the jet chamber, it should be placed if possible in front so that the level in the jet is raised when the car is climbing. If the jet level is lowered when the car is climbing the engine may

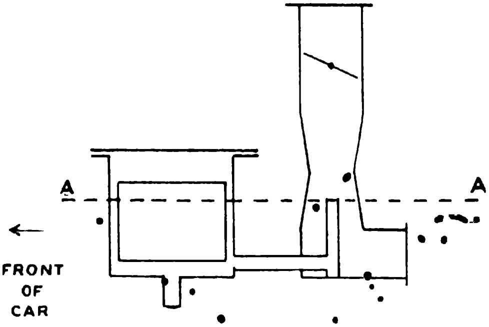


FIG. 45.—Petrol level in carburettes.

stop, which possibility is the reverse of desirable. In the arrangement with the float chamber in front and the car on the level, the petrol level in the float chamber and jet would be at A-A, Fig. 45. When going up hill, the level is shown by the dot and dash line C-C, Fig. 46; and for down-hill work by the level B-B. Even with the crosswise arrangement, if the car is left stationary on the camber of the road loss of petrol through the jet overflowing can occur.

Where the petrol does not flow by gravity to the float chamber, the pressure of the exhaust or of air supplied by an air pump is utilized to force the petrol to the float chamber. These systems do away with the possibility of failure of supply when the car is on a gradient.

Symptoms.—Flooding, the term used to indicate leakage from the jet, can be caused by setting the jet too low in relation to the level in the float chamber, the remedy being to use a longer nipple or to insert

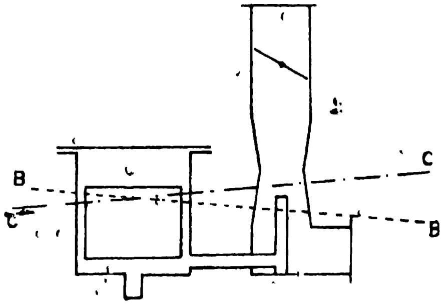


FIG. 46.—Petrol levels on gradients.

a washer at the base of the existing nipple. A needle valve, in want of re-grinding, by imperfectly closing on to its valve seat will allow leakage, and if the float, toggle levers, or valve rod get jammed in any way when the valve is off its seat a leakage will always occur. Beside this leakage, which may exist when a car is still, violent oscillations of the needle valve take place when a car is moving over a bumpy road or an engine is vibrating badly. In the running of the engine, a rich mixture will enter the cylinder, resulting in a tendency to overheating, and a lack of accelerating power will manifest itself when the throttle is opened quickly.

A rich mixture, not due to flooding, before it is cured, will call for the substitution of a nipple with a smaller orifice.

A weak mixture not infrequently is due to the presence of air finding its way into the induction pipe through badly made joints; and where an auxiliary spring-controlled air-inlet is used through the spring being too weak. The size of the jet orifice can be increased as one means of getting a normal mixture. With a very weak mixture, the charge burns slowly and may last until the inlet valve opens for a fresh charge to enter the cylinder, in which case the new charge is fired, the slight explosion passing down to the carburetter, a phenomenon known as "popping".

Irregular action of an engine, the ignition being perfect, is due either to spasmodic choking of the fuel supply, or due to "freezing". The latter can be cured by warming the air supply either by the exhaust gases or by the circulating water.

Attention is now being directed to means other than the use of the suction of the engine for supplying the fuel, but with engines using spirits or light oils no success can as yet be recorded. With heavy oils, and in the larger engines used for stationary work and marine propulsion, forced feed is successfully employed, and no doubt in time smaller engines will follow suit.

CHAPTER VIII.

LUBRICATION AND LUBRICATING SYSTEMS.

When one surface moves relatively to another friction occurs and the work done in overcoming friction is changed into heat energy. In order to reduce the friction and the consequent wear in the moving parts, these parts are lubricated by maintaining a film of oil between them. So far as we are at present concerned with the lubrication of the engine and its accessories, the pairs of moving parts are: (1) the piston and cylinder walls; (2) the small end of the connecting rod and the gudgeon pin; (3) the big end of the connecting rod and the crank pin; (4) the crank shaft journal and the main bearings; (5) the cam shaft and its bearings; (6) the driving shafts of the pumps and magneto and their bearings.

The systems employed whereby all these parts are effectually lubricated are three in number and comprise:—

1. Splash.
2. Pressure *or* Mechanical.
3. Combined splash and pressure.

Splash.—This is the simplest and cheapest of the three systems. In this case the crank case is supplied with oil into which the big ends dip and throw the oil up on to the cylinder walls and interior of the piston to the gudgeon pin. The oil which drains down is directed to the main bearings.

Sometimes the piston has ledges for collecting oil, which then passes through holes in the piston to the cylinder walls, in other cases a projection on the under side of the top of the piston collects the oil, and directs it to a hole in the small end of the connecting rod whereby the gudgeon pin receives its lubricating oil.

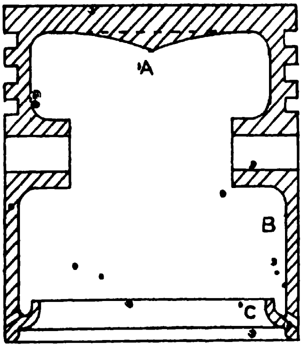


FIG. 47.—Piston with oil collectors.

Fig. 47 gives a construction of piston providing both these features. The oil drops from the point A and gets to the gudgeon pin through a hole in the small end. From the bottom of the ledges C oil passes through holes D in the piston walls B to the cylinder wall. This construction is rarely used now since light pistons are more important.

Owing to the fact that a considerable amount of oil gets past the piston rings into the upper part of the cylinder and is then burnt up, the oil in the crank case must be periodically replenished, this being usually effected by means of a hand-pump situated on the dashboard. The pump has a two-way cock which enables the oil to be drawn from a tank and forced into the crank case. The great disadvantage of this system is the lack of uniformity, the engine being probably over-lubricated at the time a fresh charge is put into the crank case, with accompanying smoky exhaust, and under-lubricated by the time a further charge is given.

Pressure or Mechanical.—In this system oil is forced to all the working parts by a pump, the oil being drawn from a sump in the lower part of the crank case and forced through a tell-tale or indicator on the dashboard to the main bearings, whence it passes through the crank shaft to the big ends, passing to the gudgeon pin and then to the cylinder walls from which it drips back into the sump. The method of carrying out the system varies, in some cases the connecting rod is drilled, in others the rod carries a small copper pipe for conveying the oil from the big ends to the gudgeon pin; again, the crank shaft is hollow in some constructions whilst in others the shaft is drilled, the ends of the ducts being carefully plugged.

The advantages of the pressure system are: (*a*) the possibility of using smaller bearings; (*b*) the oilways are less liable to be choked or stopped; (*c*) regular, regulatable, small quantities of oil can be used, so that over-lubricating does not take place. The disadvantages are: (*a*) any failure of the system is liable to produce complete breakdown of the engine; (*b*) the viscosity of the oil and the pressure varies with the temperature, and (c) the amount of oil getting to various parts depends on the condition of the main bearings; if the pressure is high enough to maintain a film of oil when the bearing is tight then too much is thrown off when the bearing is slack, and vice versa.

Combined Splash and Pressure.—Only the main bearings are supplied with oil under pressure, the oil passing freely from them to troughs into which scoops on the big ends dip and thus spray the cylinder walls and remaining parts. The troughs are kept full, so that a uniform lubrication is obtained, the overflow passing to the sump from which the pump obtains its supply. An improvement is obtained by coupling the lubricating regulating means to the throttle, so that the supply is approximately proportionate to the load. One easy method consists in fitting the troughs with vertically moving weirs operated in common with the throttle, thereby regulating the depth of immersion of the scoops. A similar method consists in pivoting the troughs at one end, and raising or lowering the free end by rods also coupled to the throttle control lever. A drain cock must be fitted to the bottom of the sump and a second cock can be used as an overflow.

This system is illustrated in Fig. 48. It will be noted that the leads to the main bearings are partly pipes and partly ducts in the supporting webs.

Lubricating Pumps.—Two main types are used, the geared pinion or Roots Blower, and the piston or plunger type.

The geared pinion type shown in Fig. 49 is driven by a vertical shaft and helical gearing from the cam

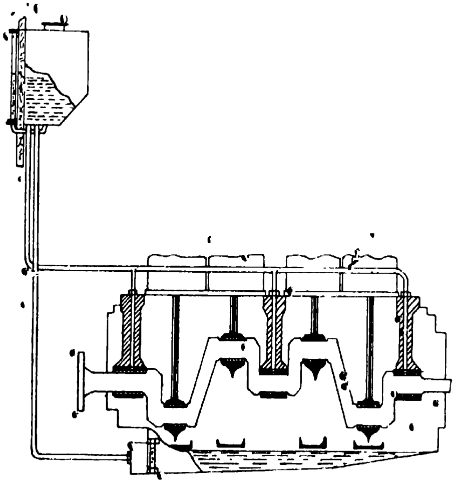


Fig. 48.—Lubrication system.

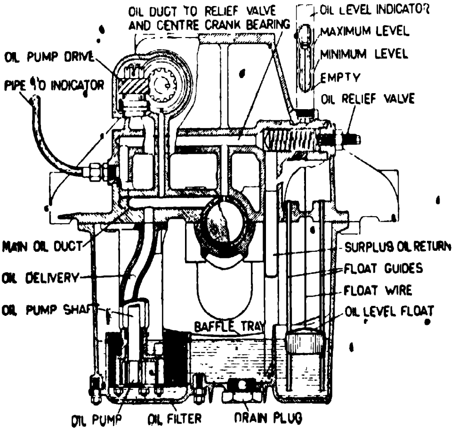


Fig. 49.

shaft, the pump being placed at the bottom of the sump. Ample provision for filtering the oil and a float indicator are provided. These pumps are very satisfactory when operating under small suction and in positions where they are always primed.

The cam-operated plunger pump, of which type an example is given in Fig. 50, has a considerable vogue. The plunger A is hollow and contains a spring S which effects the outward and suction stroke. The cylinder and valve casing B are integral and bolted to the crank case C on a level with the cam shaft. The crank case is cast with ducts D which form the delivery passages to the main bearings. Ball suction and delivery valves are used.

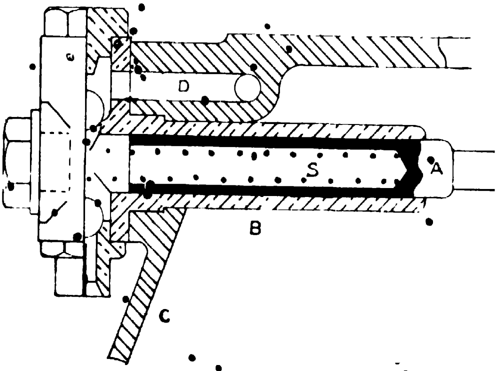


FIG. 50.—Cam-operated plunger pump for oil.

CHAPTER IX.

MAGNETOS AND ACCUMULATORS.

THE charge of gases is fired electrically by a spark which is produced between the points of a sparking plug. At the present time the high-tension magneto is almost universally employed for obtaining the supply of electricity, although an additional source is obtained from an accumulator.

It is now proposed to briefly describe and indicate the functions of the main element of the magneto. One of these elements is the magnet which for the sake of convenience takes the form of a horse-shoe. It is made from special steel which combines the property of steel for retaining its magnetism or remaining "permanent," and that of soft iron which can be more highly magnetized but loses its magnetism more quickly. The magnet retains its magnetism as long as the armature, or a keeper of iron, connects up the north and south poles. By placing two or three magnets side by side, each of which is laminated, i.e. made up of thin strips, the complete magnet is less liable to become de-magnetized. Soft iron pole shoes which enclose the armature are bolted to the poles of the magnet.

The armature is of H section, made up of thin sheets which are insulated from one another to prevent cross-currents (or surgings) from existing, and are bolted to end plates which have spindles adapted to rotate in ball-bearings. The armature is trued up in a lathe so that the gap between it and the cylindrical surfaces of the pole shoes is as small as possible, about $\frac{1}{100}$ inch. Upon the armature two sets of wire are wound, one, the primary, consists of two or three layers of silk insulated copper wires, and the other, the secondary, consists of about forty layers of much finer wire, superposed on the primary layers. The layers are insulated from each other. A section showing the winding is given in Fig. 51. As the armature is rotated, the magnetic influence passing through the core of the armature varies in intensity from a maximum to a minimum twice per revolution, and this variation produces an electric current of small electro-motive force (E.M.F.).

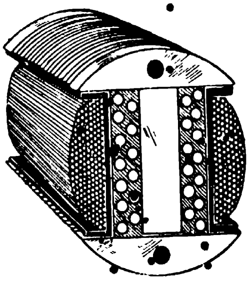


FIG. 51.

By suddenly breaking the primary circuit a very high E.M.F. is momentarily generated in the secondary circuit. Forming part of this circuit is the sparking plug. The air gap between the plug poles has a great electrical resistance and can only be bridged with a formation of a hot spark at the moment of the existence of the high E.M.F. If therefore the contact-breaking device of the primary circuit be mechanically operated at regularly recurring intervals, then a spark will also be regularly produced. The "make and break" device or *contact breaker* is mounted on or driven off the armature spindle.

The condenser is made up of tinfoil sheets insulated from each other, alternate sheets being earthed or connected to the primary winding. It is used to

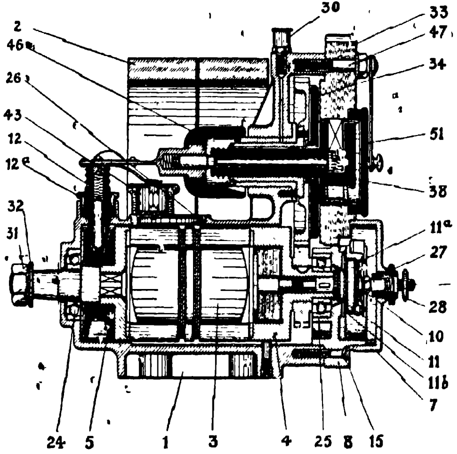


FIG. 52.—U.H. magneto.

obtain a more rapid and complete break. When the primary circuit is broken it would not ordinarily become instantaneously zero, but when a condenser is fitted the current is more rapidly absorbed in the tinfoil and a condition approaching an instantaneous break is obtained.

The secondary circuit is coupled to the spindle of a distributing device consisting of alternate metal segments and insulating material, whereby in engines with more than one cylinder the sparking plug of each cylinder is connected up in its proper firing order.

The speed of the armature for three-cylinder motors should be three-quarters the speed of the crank shaft; for four-cylinder motors the armature should be driven at the speed of the crank shaft; and with six-cylinder motors at one and a half times the speed of the crank shaft.

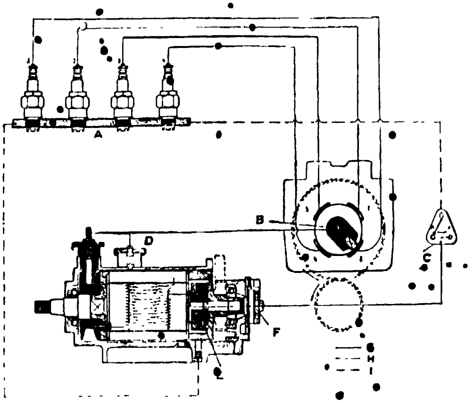


Fig. 53.—Wiring diagram for four-cylinder engine. A, sparking plugs; B, distributor; C, switch; D, safety gap; E, condenser; F, contact breaker; G, primary circuit; H, secondary circuit; I, earth or frame circuit.

The U.H. magneto which is shown in Fig. 52 gives the parts, already referred to in their assembled positions, and in Fig. 53 we have the various details of wiring connexions between the magneto, distributor, and plugs.

The following description of the magneto, the method of timing, and of locating troubles in magnetos has been supplied by Messrs. S. Wolf & Co.

Assuming the magneto to be fitted with timing adjustment, first set the timing lever to full advance, by turning it round as far as it will go in the opposite direction to that of the armature's rotation. Turn the armature round in its proper direction, as indicated by the arrow, until the platinum contacts move apart; this brings the armature into the correct position for full advance of ignition. Now look through the openings in the distributor, plate 33, to see on which H.T. segment the distributor brush is; note the number of this segment, which corresponds with the number on the upper edge of the distributor plate, and connect the plugs of the cylinders by their cables to the magneto in the order in which they are to fire, so that the numbers on the upper edge of the distributor plate correspond with the numbers of the motor cylinders. Then that piston whose cylinder and plug are connected with the H.T. segment and distributor brush is put into its position of full advance ignition; the driving wheels are then put properly into gear and the toothed wheel is tightened up on the armature spindle.

The contact plugs of the distributor are then connected with the ignition plugs by well-insulated rubber cables of not less than 9 mm. diameter, and the short-circuiting terminal 27 is connected by a rubber-insulated cable of not less than 5 mm. diameter with a switch, one pole of which must be connected with the frame.

Regard must always be had to the direction of rotation. If this is for right-hand drive (clockwise), the position of full advance ignition is that in which the armature is 1 mm. from the left-hand pole shoe. On the other hand, if the magneto is for left-hand drive (anti-clockwise), the position of full advance ignition is that in which the armature is 1 mm. from the right-hand pole shoe, and in this position the gear wheel or coupling must be tightened up on the spindle, assuming the motor to have been set as above explained.

Cutting off Ignition is effected by a switch. When the switch is open, the magneto is ready to work; when the switch is closed, the primary winding of the armature is short-circuited and the magneto is put out of operation.

Safety Spark Gap, 43.—This provides a path for the escape of the high tension current if the magneto should become accidentally disconnected from the plug, or if the electrodes of the plug should be too far apart. The magneto must not, however, be run for any length of time with the spark discharging across the gap.

Contact Breaker.—This consists of the interrupter 11 with platinum points 11*a*, and the adjusting nut 11*b*.

The contact-breaking mechanism is subject to no wear, as there are no pivots, and all screw threads that could give rise to defects by working loose are avoided.

To adjust the make and break, first slacken the contact-breaker fixing screw and draw the contact breaker out slightly. Then turn the notched adjusting nut 11*b* at the back of the contact breaker towards the right or the left as required, by means of the spanner key, until the right amount of interruption is secured at the platinum contacts 11*a*. After the contacts have been adjusted, tighten up the screw again.

Locating Troubles.—Irregular firing is generally due to there being too great a gap between the electrodes of the plug, assuming of course that the cable connexions are in order. The electrodes should not be more than 0·6 mm. apart, and this matter should be put right if necessary.

If the firing is still irregular or fails, proceed as follows to examine the magneto for proper action.

Disconnect the igniting plug cables from terminals 1, 2, 3, 4, and the switch cable from terminal 27, and by means of plug or clip contacts connect wires to terminals 1, 2, 3, 4, and place the ends of the wires close to the magnets, so as to form a spark gap of about 1 mm., the timing lever being set to full advance, i.e. in the end position opposite to that of the direction of rotation. Now run the magneto at not less than 60 revolutions per minute in the direction for which it is built. If sparks pass at the spark gaps by the terminals 1, 2, 3, 4, the magneto is in order, and the trouble is in the plugs or in the switch or in their connecting cables. The part in which the trouble lies can easily be found by changing. On the other hand if no sparks pass at the spark gaps by the terminals 1, 2, 3, 4, the magneto requires attending to, and the platinum contacts 11*a* of the contact breaker 11, the carbon brush holder 12, its brush and collector ring 5 should be cleaned with pure petrol. Also remove the distributor plate

33, and clean the contact segments. If, after these parts have been thoroughly cleansed with petrol, dried and properly replaced, the magneto still fails to work correctly, the winding is at fault. If it should be necessary to dismantle the magneto, proceed as follows: Remove the gear wheel or coupling by means of a wheel-dismounting tool, and unscrew the carbon brush holder 12. Then remove the cover 7 from the bearing, take out screw 10 and remove the contact breaker 11, unscrew the distributor plate 33, and remove the distributor gear wheel. Then unscrew the rear bearing and draw the armature 3 carefully out from the pole shoes. All the parts should then be carefully examined and cleaned. Owing to the design of the magnet frames it is not necessary to short-circuit the poles with an iron plate or bar when the armature is removed, but care should be taken that the magnet frame is not in the neighbourhood of masses of iron, as otherwise loss of magnetism occurs. To reassemble the parts, proceed in the reverse order to that described. The fixing screws of the bearing must be well tightened up. Before screwing in the carbon brush holder 12, see that the carbon brush moves easily in its socket, and also that the carbon brush of the switch terminal 27 on timing lever or cover 7 works easily, so that a good rubbing contact is ensured.

Accumulators. — Accumulators, or as they are sometimes called "Storage batteries" or "Secondary cells," have the power of storing electricity after having been charged therewith and of giving out such charge as may be required.

The lead accumulators comprise a number of grids or plates containing in a pasty form either lead oxide (positive plates) or red lead (negative plates). These are placed in a celluloid cell and immersed in dilute sulphuric acid. The density of the solution is about 1·2. When completing the solution pure distilled water or acid should be added until a final solution is obtained of the required density. Each cell when fully charged is under a pressure of two volts, so that two are usually connected in series to give four volts. The rate of charging is about six amperes per square foot of positive plate surface.

In order to convert the low voltage, or E.M.F. into the higher one necessary for ignition purposes, an induction coil is used. This comprises two sets of windings on an iron core similar to the windings on the armature of a magneto. The "make and break," condenser, and distributor when fitted are also similar. Most coils have a trembler blade fitment which operates in a manner analogous to an electric bell.

There is a second type of accumulator which has only recently been perfected. The plates are of nickle hydrate and iron oxide contained in a steel shell and immersed in a solution of caustic potash. These alkaline cells are stated to be capable of very rough mechanical and electrical treatment without being materially injured thereby. They can be discharged by short-circuiting across the terminals, or can be charged at ten times the normal rate of discharge and will not be affected, in which respect they are very much superior to the first type. They have, however, a working E.M.F. of only about 0·9 volts per cell.

CHAPTER X.

COOLING SYSTEMS.

Of the heat which is generated in the cylinders, part passes away with the exhaust gases, part is converted into useful works, and the remainder, about 35 to 40 per cent, passes by radiation to the cylinder walls, from which it has to be carried away in order to prevent overheating.

Air.—With small-powered engines, radiating fins are cast on the cylinders over which air passes and takes up the heat. The current of cooling air may be produced by the passage of the car through the atmosphere or may be induced by a fan. With small-powered cars this form of cooling is fairly efficient. The great objection to air cooling arises from the fact that when a car is climbing so that the engine is developing its maximum power and the speed of the car is low there is a tendency to overheating.

Water Cooling.—When water is used as the cooling medium, it is circulated through water jackets surrounding the cylinders, either by a pump or by thermo-syphonic action. The heat taken up by the water is dissipated by passing the water through a radiator. When a pump is used, it is situated near the bottom of the radiator, its delivery pipe passing to the bottom of the jackets. The water is pumped from the bottom of the radiator through the jackets and thence by pipes to the top of the radiator. The pump is usually driven off the end of the cam shaft, or by skew or like gear from the timing gear. Fig. 54 is a diagrammatic sketch of such a system, the pump A has a delivery pipe B which branches to the pair of castings F. The pipe C goes to the top of the radiator D and is connected thereto by rubber or other flexible tubing. The radiator has a filling cap E and drain plug G.

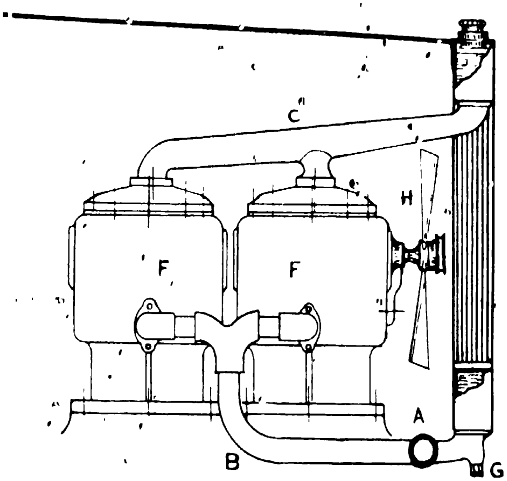


Fig. 54.—Water-cooling system.

There are six types of pumps in more or less common use:—

(a) The Roots' Blower or geared pinion such as that illustrated in Fig. 49, Chapter VIII. The capacity of such a pump varies as the speed.

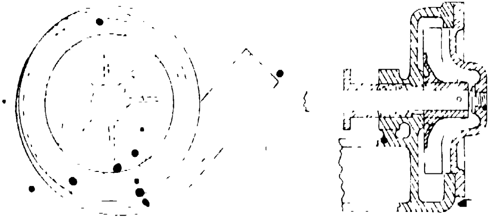


Fig. 55.—Centrifugal pump.

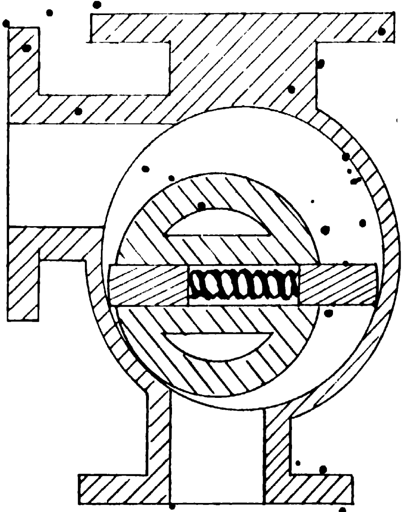


Fig. 56.—Eccentric disk pump.

(*b*) The Centrifugal Pump as illustrated in end view and sectional front view in Fig 55. The capacity of this type of pump, after a certain speed has been exceeded, varies approximately as the square of the speed.

(c) The Eccentric Disk, with sliding piston. This type has been illustrated in Fig 56. The pistons are carried by a disk which is eccentrically mounted in the pump casing and are pressed by springs against the casing. The hollow part between the disk and casing is thus divided into two parts alternately connected with the suction and delivery orifices.

(d) The Helical or Screw Pump. This has the advantage that if the pump stops working the system will automatically become thermo-syphonic.

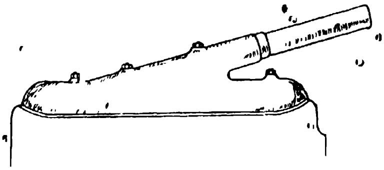


Fig. 57.—Uptake pipe for monobloc engine.

(e) The Diaphragm Pump. This requires no gearing to drive it, a spring-controlled diaphragm being operated by fluctuations of the exhaust pressure. No British car has been fitted with this form of pump.

Thermo Syphon Circulation.—When water is heated it expands and its density decreases, so that in a closed system warm water tends to flow upwardly and cold water downwardly. This physical fact has been put to practical use on cars. By connecting the upper part of the cylinders with the upper part of the radiator through large pipes, the warm water in the jackets rises to the radiator, is there cooled and sinks to the bottom, whence it passes to the bottom of the cylinder jackets. The form of uptake for a monobloc engine is as shown in Fig. 57. It is secured to the casting by four studs and nuts. The pipes must be large so as to impede the flow of water as little as possible. For the same reason any change in direction must not be abrupt but produced by gradual change.

It may be noted in passing, that it has been proposed to dispense with a radiator and cool the water by using air which is drawn by the water circuit injector action.

Radiators.—There are two kinds of radiators:—

1. Honeycomb.
2. Tube.

In radiators of the first kind, the water is contained in thin cells, air being drawn through the honeycomb-like spaces between the cells. A very large surface, requiring the use of a smaller quantity of cooling water is the principal advantage, against which can be set the liability to leakage at the cell joints.

Tube.—These comprise a lower and an upper tank connected by a number of vertical tubes similar to that shown in Fig. 54. When there are side tanks, the tubes are horizontal. The water flows through the tubes either in series or in parallel, the latter being the more usual arrangement. In the majority of cases, the tubes are provided with fins, which are soldered on or are pressed on, their function being to provide a larger cooling surface and assist in radiating the heat.

Usually the radiator is placed in front of the engine, but the practice is growing of placing it at the rear of the engine, immediately in front of the dashboard, where it is less liable to damage due to collisions. This arrangement necessitates the complete closing in of the under part of the engine so that the induced air must go through the radiator. For the sake of rigidity the radiator is mounted on a special cross frame, the seating having leather, rubber, or wood cushions. To minimize the effects of frame distortion, a ball and socket connexion with the side members of the frame is not infrequently provided. As a further consequence of frame distortion and also because of the expansion of the water pipes under running conditions, the radiator has to be coupled to the pipes by rubber or other flexible tubing.

Fans as shown at H in Fig. 54 are fitted to ensure a draught of air passing through the radiator when the engine is running, although the car may be stationary, and to increase the cooling effect when the car is moving. Fans placed behind the radiator are being replaced by vanes fitted to the periphery of the flywheel, an arrangement which goes well with radiators fitted behind the engine.

In addition to having pipes with large bends for the purpose of obtaining an easy flow, the bends should also be arranged that there are no pockets wherein air could accumulate and form air pockets, or in which steam could be produced. When the water is drained off, it is also essential that none is left in any elbows.

When water freezes as it does at a temperature of or below 32° Fahrenheit, the ice which is formed has a volume which is 10 per cent greater than that of the original water. In expanding great force is exerted, sufficient to crack the water piping or cylinder jackets.

Suppose a car in a garage the temperature of which is likely in the winter to fall below the freezing point, either the water has to be drained from the cooling system, or some substance must be added to it, such as glycerine or other anti-freezing mixture, which has the property of lowering the freezing point. Such treatment is also desirable in cold climates such as Canada.

The following table was given in "The Autocar" some time ago, which shows the effect of different quantities of glycerine in this respect:—

Proportion of Glycerine.	Freezing Point. Fahrenheit.	Specific Gravity.
10 per cent	28°	1·027
30 ,,	15°	1·080
40 ,,	5°	1·100
50 ,,	- 5°	1·130

CHAPTER XI.

TRACTION.

Adhesive Power.—If a wheel carrying a load W, Fig. 58, be rolled over the ground and k is the coefficient of friction between the wheel and the road, then the maximum tangential force which can be applied to the rim of the wheel is $k \cdot W$. This force $k \cdot W = P$ is called the "adhesive power". The coefficient k is approximately equal to 0·6 for rubber and macadam.

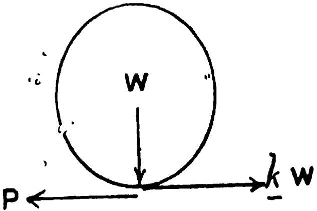


FIG. 58.—Adhesive power.

In determining the adhesive power P for a given car the rear wheels B of which are driven, let W be total load on the wheels with the centre of gravity in the position shown in Fig. 59, then

$$P = 0.6 \cdot H = 0{\cdot}6 \frac{a}{a+b} \cdot W.$$

Going up a hill, the disposition of the weight relative to the wheels becomes altered. The diagram

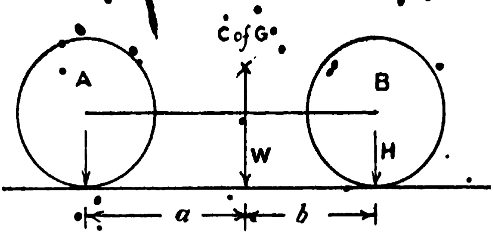


Fig. 59.—Proportion of load on back wheels.

Fig. 60 gives the new values of a^1 for a and b^1 for b, so that the new adhesive power becomes

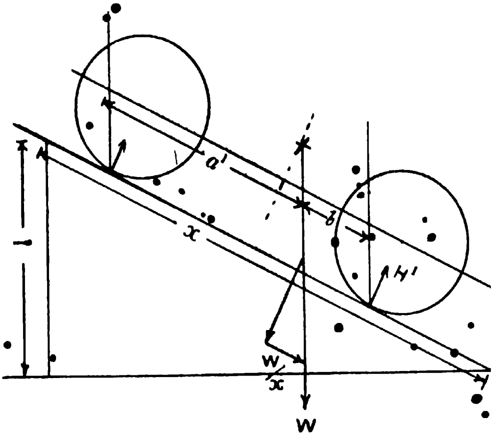


Fig. 60.—Car on gradient—forces involved.

$$P^1 = \cdot 6 . H^1 = \cdot 6 \frac{a^1}{a^1 + b^1} W = \cdot 6 \frac{a^1}{a + b} . W.$$

If a^1 is greater than a when a car is proceeding up hill then the adhesive power is greater, a valuable feature since the tractive force can be increased as will be seen later.

Tractive Force.—In order to make a car move a force has to be applied to the road wheels by the engine through the medium of gearing sufficient to overcome the resistances to motion. This force must not exceed the adhesive power or the wheels will spin round without gripping. The factors concerned in determining the tractive effort are: (1) the torque of the engine; (2) the friction in the transmission mechanism; (3) the gear ratio between the engine and the back wheel; and (4) the diameter of the wheel.

Using the formula given in Chapter IV—

$$\text{B.H.P.} = \frac{2\pi \,.\, \text{T} \,.\, n}{33000}$$

we get the torque = $\text{T} = \dfrac{\text{B.H.P.} \times 33000}{2\pi \,.\, n}$

On the top gear, which is usually direct, the transmission system absorbs about 8 per cent of the power, whereas on the other gears about 20 per cent is absorbed, so that 92 per cent and 80 per cent respectively of the engine power is available at the back axle. The gear ratio R equals the revolutions per minute of the engine divided by the revolutions of the road wheel, an average case being 3·85 to 1 for the top gear, for the second gear 6·0 to 1 for the first gear and 12 to 1 for the low gear.

Let T be the engine torque in lb. feet, R be the gear ratio, E the efficiency, W the weight in tons on the rear wheels, and D the diameter in feet of the road wheel. Let F be the tractive force in pounds per ton.

Then $F = \frac{T \times R \times E}{\frac{D}{2}}$, but F must not exceed 0·6 H, otherwise slipping will occur.

Resistance to Motion.—Now the resistances which this tractive force has to overcome are three in number for a car travelling on the level road, to which has to be added a fourth factor when the car is on a gradient. The first factor is that of *road resistance*, which may be taken as equal to 40 lb. per ton weight. The second feature is that due to *mechanical friction*, which varies as the speed of the vehicle. The third is due to the *air resistance*, which is proportionate to the square of the speed and equals $\cdot 0025 \,.\, A \,.\, V^2$, where V is the speed in miles per hour and A is the projected area of the car in square feet. The fourth factor, that due to gradient, is equal to $\frac{W}{x}$ where $\frac{1}{x}$ is the gradient, as illustrated in Fig. 60, and W is the weight of the car; this resistance can be obtained graphically as shown in the bottom part of the figure by finding the resolved part of the vertical force W in a direction parallel to the inclined road.

Brakes.—It would be as well to consider at this stage the mechanics of brakes since very similar calculations are required. Suppose a car of weight W lb. to be moving with a speed of v feet per second, its kinetic energy will be $\frac{Wv^2}{2g}$. If it is desired to bring the car to rest within a distance d feet by applying the brakes on the driving wheels, and using the maximum braking force of 0·6 H, where H is the load on the wheels, we get as energy absorbed

$$0\cdot6 . \text{H} . d = \frac{Wv^2}{2g}$$

The hub brakes will take the braking power equally, the necessary maximum tangential force which should be applied to each brake rim being $\frac{\text{Diameter of wheel}}{\text{Diameter of hub}} \times \frac{0\cdot6 . \text{H}}{2}$. It follows that the normal pressures of the braking surfaces against the brake drums is equal to this tangential force divided by u, u being the coefficient of friction, which pressure the cam actuating gear must be designed to give.

Question 1.—An engine is turning at 1200 revolutions per minute when propelling a car at 35 miles per hour on top gear. If the road wheels are 32 inches in diameter, what is the gear ratio?

Question 2.—What H.P. is required to move a motor van weighing 3·5 tons at 12 m.p.h. along a level road, the tractive force to overcome all the resistances being 55 lb. per ton?

Question 3.—If the car in Q. 2 were to climb a hill of gradient 1 in 13 at the same speed, what extra H.P. is required?

CHAPTER XII.

FRAMES AND SPRINGS.

THE main frame upon which the engine, transmission gear and body-work is mounted is itself carried by springs on the front and rear axles. Two side members A, shown in Fig. 61, and a number of cross members constitute this main frame. The shape is dependent on two factors, namely the load (this includes not only the dead load but also the manner in which it is distributed), and the provision of ample facilities for the parts moving relatively thereto to perform their movements.

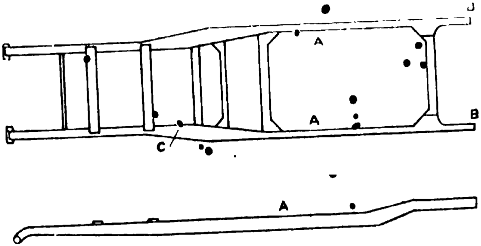


FIG. 61.—Main frame of chassis.

In order to comply with the latter condition the side members are inswept at the front to provide a good lock for the steering wheels, and not infrequently swept up over the back axle so that the movement of the back axle relative to the frame is possible whilst at the same time the frame as a whole is kept low, and large diameter wheels may be used.

When heavy bodies are to be fitted, keeping the centre of gravity as low as possible must be remembered as an important feature in the design.

Since abrupt changes in direction are a source of weakness it is usual to construct the members A at such positions C with webs which are either integral therewith or riveted thereto.

Looking at the side view of the frame, it will be seen that the depth of the members A is greatest

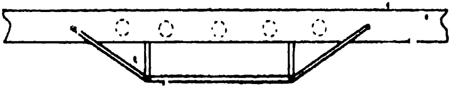


FIG. 62.—Trussed side member.

in the centre, the reason for this being that these members are acting as loaded beams and have been designed accordingly. A bending moment and shearing force diagram should be drawn whenever the necessary data is obtainable. The torsional forces to which the members A are also subjected is not inconsiderable, but their value is difficult to estimate, and the factor of safety used is large.

As an alternative to deepening the side members at the position of maximum bending, light girders may be employed as shown in Fig. 62, and where lightness is a consideration, holes are drilled along the neutral axis as indicated in dotted circles.

The ends B of the members A are extended to form the dumb irons to which the springs are pivoted or shackled, and also for carrying the petrol tank in cases where the latter is attached to the rear of the frame.

Rolled channel steel sections, Fig. 63, are stronger at the root than the usual pressed steel section, Fig. 64, now employed for side members. The resistance of the pressed steel section to torsion is therefore not so great as the channel form, and argument has been forthcoming to show that this is in its favour

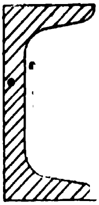


Fig. 63.—Section through rolled channel steel side member.

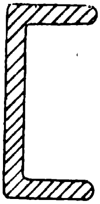


Fig. 64.—Pressed steel side member.

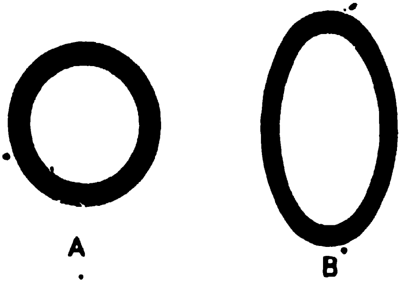


Fig. 65.—Sections tubular side members.

since it can give and not break under these forces. Steel tubes, having a section as shown at A and B in Fig. 65, are not now used for side members except in very small and cheap cars but are used for cross members. Another section which is useful for constructional purposes is of inverted **U** shape with flanges as shown in Fig. 66.

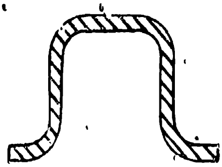


Fig. 66.

Cross members as shown are used to stiffen the frame, some of them being also made to act as supports for the radiator, engine, brake and clutch actuating pedals, gear-box, torque rods, and similar parts.

Considering, in the order set out, these cross members, the modern arrangement provides not so much for the support of the radiator but for the maintenance of a constant distance between the side members at this position.

Whether the engine is carried by cross members, by lugs or on a separate sub-frame, the suspension is usually on the three-point system. One method of putting this into practice consists in pivoting the front lug A, Fig. 67, to a cross piece *ab* and bolting the rear lugs CD to the cross piece *cd*. By so mounting the engine the crank case and other parts do not become strained when the main frame is distorted.

Springs.—As far as possible, the main frame is insulated from shocks likely to cause distortion. To this end springs are interposed between the frame and the front and back axles respectively.

Mechanical and fluid springs have been used, the former being almost universal. Of the ordinary subdivision of mechanical springs into the spiral and the laminated types, only the latter need be considered.

Beside yielding to shock the springs have to absorb the energy and quickly damp the oscillations set up, and it is because laminated or leaf springs possess this property that they have been adopted.

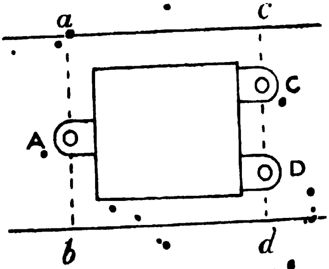


FIG. 67.—Three-point suspension.

Where n is the number of leaves forming a laminated spring,

w is the width of each leaf, and

t is the thickness.

Also L is the overall length of the spring, and

c is a constant = 54000.

Then d the deflection in inches per ton load is given by

$$d = \frac{L^3}{w \cdot t^3 \cdot n \cdot c}$$

and

$$W \text{ (the load in tons)} = \frac{w \cdot t^2 \cdot n \cdot c}{18 \cdot L\,a}$$

The number of oscillations per minute is about 90 for the front springs and 110 for the back.

Front Springs.—These are almost invariably of the semi-elliptic variety illustrated in Fig. 68, the leaves being bolted together at the centre C and to a plate A on the front axle B. The forward end is pivoted at D to the dumb iron E, and the rear end is attached to the side member G of the frame by means of a shackle F. The arrangement is such that the springs are situated immediately under the member G.

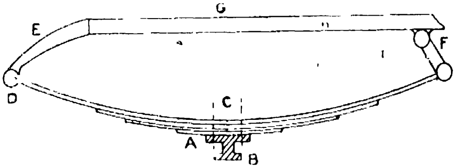


FIG. 68.—Front spring, semi-elliptic.

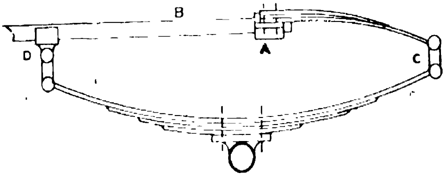


FIG. 69.—Rear spring, three-quarter elliptic.

Rear Springs.—Semi, three-quarter, and full elliptic are equally favoured, but in all cases the springs are situated outside the vertical plane of the side members. In the three-quarter set shown in

Fig. 69, the upper quarter is carried by a bracket A which is bolted to the frame B, and is connected by a shackle C to the rear end of the lower half. The forward end is shackled to a bracket D whilst at the centre it is secured to the plate on the rear axle casing.

In those cases where the springs are pivoted to the frame, it is usual to utilize the spring to transmit the tractive effort to the frame. When the rear half is so used, the spring is placed under tension, and if the front half is used the leaves are in compression.

An arrangement which is fairly common, consists in connecting the rear ends of the back springs when of the semi-elliptic type, by a transverse spring which is attached at its centre to the rear cross member of the frame.

The cantilever form of suspension comprises an inverted half-elliptic attached at the centre to the frame, one end being attached to the rear axle casing and the other, the inner end, connected by means of a shackle with the frame.

A point to notice is that the shackles and pivots must be provided with grease lubricators, and means for greasing the leaves should be provided. In the case of the shackles, the attachment to the frame more often than not is by means of what is practically a universal joint, thus giving movement in two planes.

In addition to the main springs, two others are sometimes used. *Buffers* when fitted perform the function of taking the final movement of the springs relative to the frame in cases of excessive motions.

Supplementary springs, which take the form of spiral springs fitted in place of the rear shackles, really act to take the first part of the relative motion of compression and the last part of the return movement. These springs must on no account have a periodicity which is equal to, or any simple factor or multiple of, the time of oscillation of the main springs, otherwise sympathetic vibration will result and violent oscillation of the whole system occur.

Note.—A full B.M. and S.F. diagram for the side members is given in the "Automobile Engineer" for August, 1912.

CHAPTER XIII.

FRONT AXLES, STEERING GEAR.

THE front axle is made of steel with a H-shaped cross-section.

In some forms the axle is straight as seen in front elevation, in others there is a dropped central portion to give the necessary clearance to the starting handle bracket, and in addition the ends are raised to allow for wheels of any desired large diameter to be used.

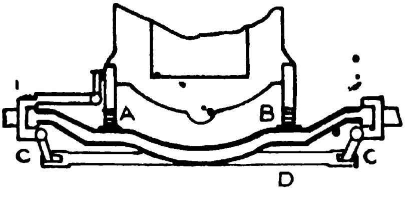


FIG. 70.—Front axle.

Such an axle is illustrated in Fig. 70. At the positions AB the upper flange is widened and stiffened to provide an anchorage for the springs.

The ends are shaped to take the steering centres of the front wheels, two kinds being in general use: (1) an open fork as in Fig. 71; and (2) a solid end drilled to take the pivot piece as in Fig. 72.

Regarded from a mechanic's point of view, the front axle is a beam loaded at four points. The shearing force and bending moment diagram should be plotted out as in the case of the side members. In addition

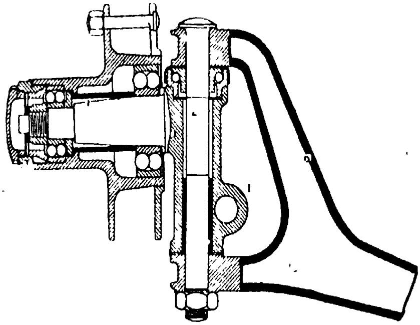


FIG. 71.—Open-ended front axle and wheel mounting.

the front axle has stand twisting forces when the car is moving; the maximum amount of twist occurs

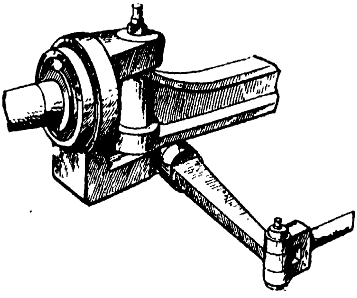


FIG. 72.—Solid ended front axle.

when one spring is under a maximum load and in its flattest condition, whilst simultaneously the other spring is under a reverse load due to a wheel being off the ground.

Wheel Mountings.—The axles for the wheels are attached to members which are pivoted to the ends of the front axle, and are in consequence of two types depending upon the form of the axle ends, see Fig. 71,

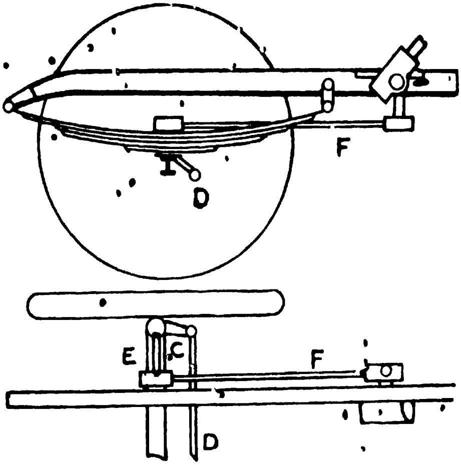


FIG. 73.—Steering connexions.

in which the axle is provided with Skefko bearings for the wheel hub, and Fig. 72.

Linkages.—These members each have a projecting arm or steering lever C, Figs. 70 and 73, which are coupled together by a rod D. The off-side pivoting member is also provided with a second lever E which is coupled by a drag link F to the steering mechanism at the bottom of the steering column.

The general arrangement of the gear just described and operating on the Ackermann System is as shown in Fig. 73, the coupling rod being behind the front axle, and the drag-link horizontal and parallel to the main side member of the frame. The drag link is usually tubular and made with a ball and socket joint connexion to the link as in Fig. 74, whereas the coupling rod is connected to the steering levers by knuckle joints (Fig. 72).

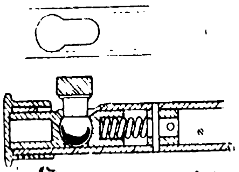


FIG. 74.—Ball and socket joint.

In Fig. 75 is illustrated diagrammatically the wheels when the car is going straight ahead, and the front wheels are also shown dotted to represent a turning movement. The Instantaneous Centre (I.C.) of the car as a whole when it is turning should be on

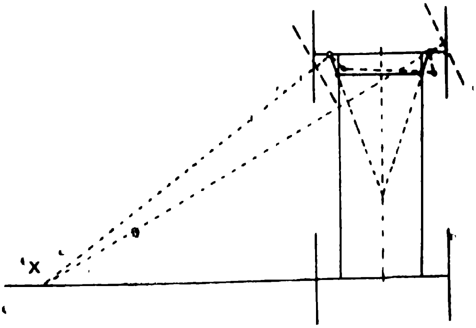


FIG. 75.—Diagram of action of steering gear.

the line produced through the back axle at some such point as X.

Suppose a rigid member such as a connecting rod to be moving so that at any given instant the direction of motion of points such as A and B be known. Let the directions be as shown. Draw lines AI, BI at right angles to these directions to meet in I. (Fig. 76).

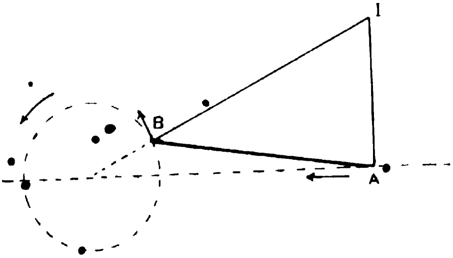


FIG. 76.—Instantaneous centre.

Consider the point A, its direction of motion is tangential to any circle passing through A and with centre on AI.

Similarly the point B for the instant under consideration could be moving on any circle passing through B and with centre in BI.

The whole rigid bar can therefore be considered as turning about a centre common to A and B, viz. I.

This centre is known as the *Instantaneous Centre.*

Similarly with a car. The radial line for the back wheels is always somewhere on the axis of the back axle. Consequently when the car is being turned the radial lines for the front wheels should intersect on the axis of the back axle, at the I.C. of the whole car.

Within certain limits this is obtainable by coupling the steering arm, so that on being produced they intersect on the back axle (the wheels being in the straight ahead position). Actually they are made so that the intersection is on the middle line of the car and about ·75 of the total distance between the two axles from the front axle.

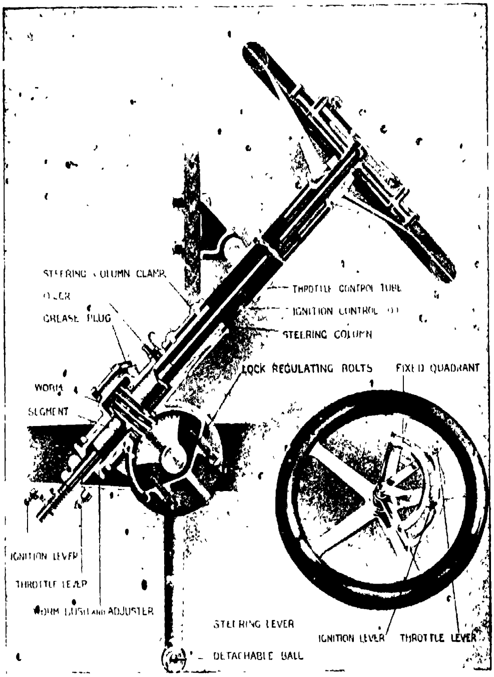


FIG. 77.

A modified arrangement consists in mounting the coupling arm in guides, so that it has a sliding movement only.

In all cases the joints and pivoted members should be adequately lubricated, and furthermore, since they are all in the front of the car and near the ground, they should be covered up to prevent dirt getting to the working parts.

Between the steering wheel itself and the drag link, and carried in a casing mounted on the off-side main frame, is the actuating mechanism which has the property of "irreversibility"; that is to say, although the steering wheel can be moved to turn the front wheels, yet the front wheels cannot move the steering wheel under the action of road impact forces. This property is very valuable since the constantly varying road shocks are not felt by the driver.

The gearing is usually of the worm and sector type as in Fig. 77. The worm itself should be so mounted, either with ball bearings or with distance pieces, that lost motions due to wear can be readily taken up. In this connexion it may be as well to note that complete worm wheels are sometimes fitted instead of a sector, so that when one part wears the wheel can be turned about to give a fresh set of working teeth.

In a second type, a nut slides up and down on a screw. The nut is prevented from turning and is provided with lugs as in Fig. 78. One end of a pivoted lever is forked to engage the lugs, the other end having the usual ball and socket joint connexion with the drag link.

Returning to Fig. 77, it may be noted that the steering rod is hollow and that through it pass the rods which operate the controlling levers of the carburetter and magneto. These rods are operated by levers moving over quadrants as shown in the plan of the steering wheel.

The method of mounting the steering box and column is clearly shown.

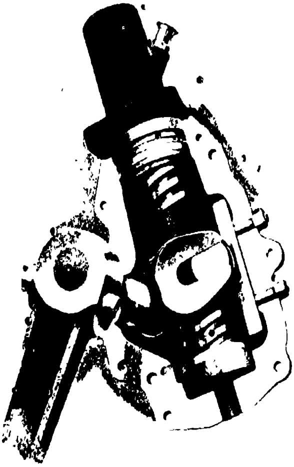


FIG. 78.

Investigation of the problem of easy steering has conclusively shown among other things that the pivot axis of a front wheel when produced should pass through the point of contact of the wheel with the ground. When this construction is adopted there results a noticeable diminution in the effort required for steering, and there is also an increased longevity in the life of the tyres.

CHAPTER XIV.

CLUTCHES.

In the general arrangement shown in Figs. 1 and 2, the first member of the transmission system is the clutch, it being the connecting link between the engine and the gear box. A clutch is defined as follows: "A clutch is a mechanism for coupling or uncoupling together two shafts one or both of which is or are in motion". In the particular case we are considering the engine shaft would be the revolving shaft and the clutch shaft either stationary or revolving according to circumstances.

The function of the clutch is to provide a means for uncoupling the primary shaft in the gear box from the engine shaft when changing gear, or under emergency conditions when stopping the car suddenly without stopping the engine, the gear lever not being in its neutral position.

In the majority of cases the clutch is bolted to, or is in part formed by the fly-wheel of the engine, the few exceptions being found on cars where the fly-wheel is fitted in front of or in the middle of the engine.

Broadly classified, there are four types of clutches:

1. Cone.
    - (*a*) Direct.
    - (*b*) Inverted.

2. Disk.
    - (*a*) Single.
    - (*b*) Multiple.
3. Expanding coil or band.
4. Miscellaneous.

It is essential that there should be a sufficient gripping power at all speeds and under severe and sudden strains, there must be no undue wear and no tendency for it to work out of gear, engagement and disengagement should occur easily and without shock. If it is intended that the clutch shall be slipped indefinitely, then provision must be made for conveying away the heat which is generated as a consequence, the calculation of the quantity of heat evolved being easily made. The action of any clutch which falls under either of the first three classes set out above depends upon the friction between two surfaces which when brought into contact have a relative motion.

In its elementary form the direct cone type comprises a conical member attached to the engine shaft, a corresponding part, and a male cone on the transmission shaft adapted to be held in engagement with it by means of a spring and to be disengaged by a lever.

In Fig. 79 a section showing the rim of the male cone member is given with a view to calculating the thrust of the spring and its relation to the dimensions of the clutch.

Let T be the thrust of the spring.

u be the coefficient of friction.

r the mean radius.

θ the half angle of the cone.

H the maximum horse-power to be transmitted at

n revolution per minute, and

P the normal pressure between the surfaces in contact.

Then, if there is no slipping,

$$H = \frac{u \, . \, P \, . \, 2 \, . \, \pi \, . \, r \, . \, n}{33000}$$

Now $\tan \theta = \sin \theta = \frac{1}{5}$ approx., so that $P = 5\,T$.

Consequently by substituting, we get an equation for T involving known or obtainable quantities.

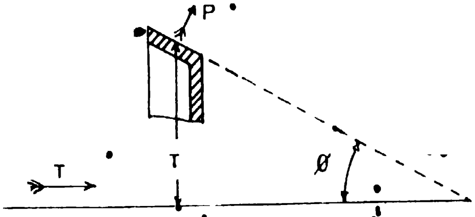


Fig. 79.

In both the direct and inverted cone types, the male portion of aluminium or pressed steel is faced with leather whilst the female part is of cast iron. The engine shaft is prolonged to form a spigot which takes into a hole, with or without ball bearings, in the transmitting shaft, thus ensuring the alignment of the two shafts. Care must be taken that the spigot bearing is well lubricated. One advantage of the inverted type, an example of which is given in Fig. 80, is that no dirt can fall upon the leather when the clutch is withdrawn, a further advantage is that it is easier to obtain a mechanism without end thrust. Many devices have been tried in order to ensure easy engagement with the cone type. In one form small flat first-intention springs are fitted beneath the leather, in another form the female part is sectionally split and in some cases small rubber rollers are placed at intervals around the periphery of the leather.

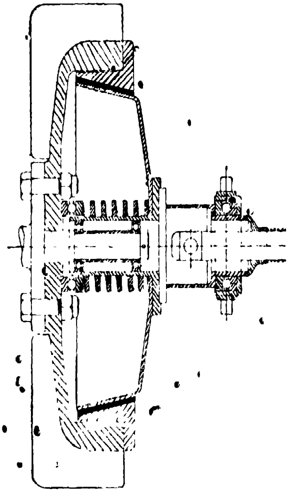


FIG. 80.—Inverted cone clutch.

A form of clutch-withdrawing mechanism which demands only a light pressure on the foot pedal is that shown in Fig. 81. It is the form used on the 11·9 h.p. Humber car. An open frame pivoted to one of the side members is coupled to the clutch and operated by the small part of the bell-cranked foot edal. This clutch has a light enclosing end piece o that it runs in oil, the leather being always in a repared state. The pedal for operating the brake nd the foot accelerator pedal are also shown. Many forms of joint provide for the sliding of

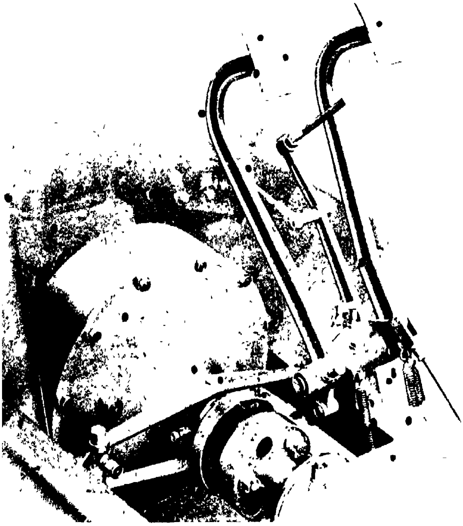


FIG. 81.—Clutch disengaging gear.

the clutch, that shown comprising four pins with curved bushes, which not only takes the drive but acts to some extent as a universal joint.

Only a few cars are fitted with single plate clutches, the best known being the De Dion and Phœnix, whereas the multiple type is commonly employed.

Multiple Disk Clutches.—Fig. 82 shows a Hele-Shaw clutch in which a number of disks made of phosphor-bronze are notched to engage keys on a casing bolted to the fly-wheel. Supported on a ball-bearing on the end of the crank shaft is a steel core B which is connected to the clutch shaft. This core has keys which engage notches in a number of steel plates, arranged alternatively to the phosphor-bronze plates. The plates run in oil, and to prevent them from sticking when the pressure is removed the outer plates are fitted with small flat springs which are in compression when the clutch is engaged. The plates are held together by a disk E under the

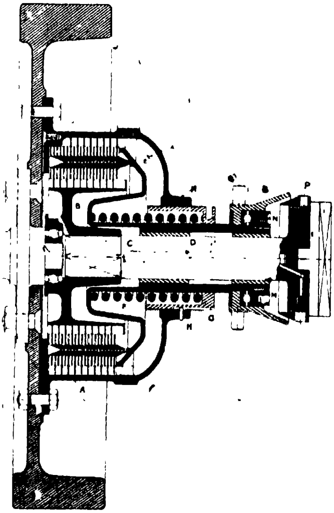


FIG. 82.—Hele-Shaw clutch.

action of a spring F, the tension of the spring being adjustable through the cap G. The clutch shaft C has a coned brake P which prevents "spinning" when gear changing.

Not a few multiple disk clutches are now made with cork insets in alternate plates, the design emanating from America.

An example of class 3 is the clutch of the Metallurgique in which the boss of the fly-wheel is formed like a brake drum and on the clutch shaft are carried expanding shoes, the friction faces being metal-to-metal. The coil clutch is based on the principle of a rope brake, the coil consisting of a lubricated steel band wound round a drum of cast iron or cast steel, the cross-section of the band not being uniform.

In the miscellaneous section may be included hydraulic clutches. In its elementary form the clutch comprises a pump and a water motor. The pump being driven by the engine and driving the motor which is connected with the rest of the transmission system. In some cases, as will be shown later, these hydraulic clutches are variable speed gear mechanisms and replace the ordinary gear box and even the differential.

CHAPTER XV.

SPEED GEARS AND BRAKES.

It follows from the subject-matter in the chapter on Tractive Force that the power given to the road wheel must vary with varying conditions. Now since there is a definite maximum output from the engine it follows that if the force exerted is to be increased the rate at which it is applied must be decreased, and vice versa.

It must also be remembered that as the engine revolutions diminish so the power diminishes, and below certain speeds this falling off in power proceeds with increasing rapidity. In the joint circumstances the engine revolutions must be kept up in order to get a big output, and yet the revolutions of the driven part must be kept low, a gearing of some sort is then necessary.

There is also another reason for using a gearing in the transmission system, as an ordinary petrol engine is not reversible, and therefore if we want to reverse the car, a reversing gear is necessary. In Chapter XVIII, dealing with other transmission systems, we shall deal with gears other than mechanical, so that it is proposed to confine this chapter to mechanical gearing. These are practically divisible into three kinds :—

1. Spur gears with quadrant control.
2. Spur gears with gate control.
3. Spur gears in constant mesh, i.e., epicyclic *but excluding* the Riley System.

In cases 1 and 2 the shafts, both main and secondary, should be kept as short as possible in order to reduce whip. The secondary shaft is sometimes known as the lay shaft. The bearings must be designed to prevent oil and grease from extruding, a large cover on the top of the gear box must be provided to facilitate inspection of the pinions, and a drain plug placed at the lowest part of the box.

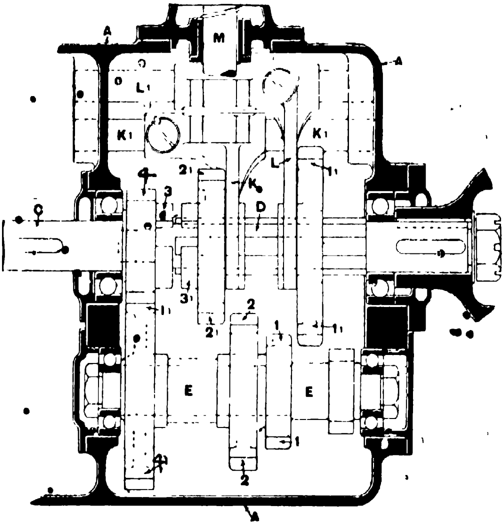


FIG. 83.—Gear box (gate change).

When gate control is adopted as in the gear box illustrated in Fig. 83, the operating lever has two movements, a sliding and a rocking movement, the design being such that the rod M, shown also in Fig. 84 at the root of the gear lever N, engages with the striking bar K when the lever is free to move in the inner part 1,R of the gate, and with the bar L when the lever is in the outer arc 2, 3. When either of the striking bars, or as they are sometimes called selector rods, is moved longitudinally, the forked arms thereon carry with them one or other of the gear wheels 2′, 1′ into engagement with the pinions 2, 1 on the lay shaft E, or the dog clutches 3, 3′ engage to give a direct drive from the clutch shaft C to the universally jointed main-driving shaft D. The shafts C, D, E have ball-bearing mountings in the gear box A. Pinions 4, 4 couple the shaft C to the lay shaft.

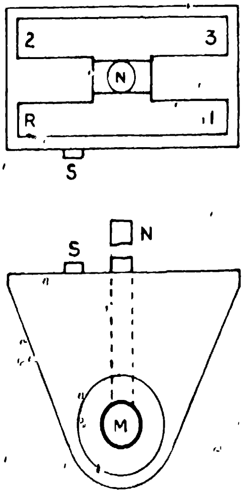


FIG. 84.—Speed lever and gate.

In order that the reverse gear may not be put in operation inadvertently, the gear lever is prevented from moving into reverse R by a stop S until a suitable catch on the rod N is lifted.

The gears themselves are of case-hardened nickel steel and the shafts for the sliding gears are either squared or castellated.

In Fig. 85 the gears and selector mechanism are clearly shown. The gear box has an extension thereon which serves for mounting the gear lever and gate. At the rear of the box a brake drum is provided for an internal expanding brake. The forward end shows the flange on the shaft with the four holes for the bushes of the clutch shaft bolts referred to in Chapter XIV.

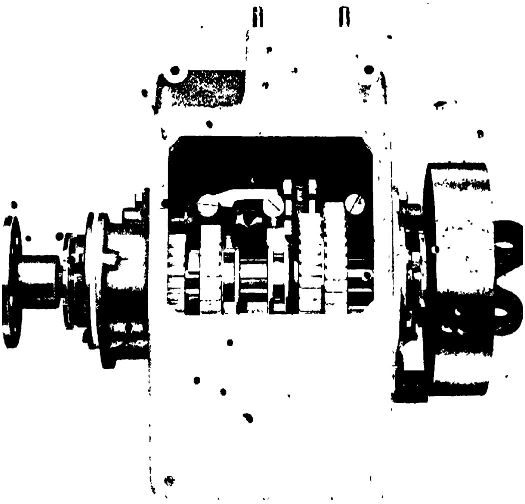


Fig. 85. Humber gear box.

With quadrant-controlled gears, the lever oscillates only in one plane, the sliding gears, permanently coupled thereto, being moved in order from first to second and second to third speed. Notches in the quadrant indicate when a gear is engaged. This control has the objection that the gears can be easily overrun and that the gear box has to be long with possible whippiness of the shafting.

Epicyclic Gear.—The mechanical principle underlying the epicyclic form of gear is dependent on the fact that the intermediate pinions, called planet pinions, are mounted on stub shafts carried by an arm or plate which is free to rotate on its axis or may be kept stationary by a brake, the two cases giving different speed reductions or reversal. These planet wheels gear with pinions on the driving and driven shafts.

When these shafts are positively locked together, the pinions and the casing rotate solidly. If the casing is braked then the drive is taken through the pinions as with an ordinary gear, and a speed reduction or reversal of the driven shaft is obtained.

Although the gears are always in mesh so that the act of changing gear can be performed silently, yet the gear itself on anything but the top is noisy. Another point which is not in its favour is that a thin oil must be used for lubricating the journals of the planet pinions, otherwise there is risk of the pinions seizing on their stub shafts. This oil has a habit of leaking along the shafting, and besides being an annoyance is wasteful and needs constant renewal.

Brakes.—Two sets are usually fitted, one at the rear of the gear box on the countershaft, and a second set on the rear wheels. In the first case pedal actuation is employed, and in the second case, a hand lever acting through compensating mechanism is used. The hand lever is mounted on the side frame member upon which is also a rack. A pawl or catch on the lever is adapted to engage the rack whereby the brakes may be kept on.

Countershaft Brakes.—In Fig. 86 the braking surface comprises shoes freely pivoted at their centres to two arms, themselves pivoted to the cross-member

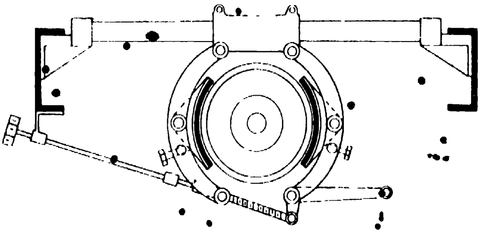


FIG. 86.—Countershaft brake.

of the frame. The free ends of the arms are coupled to the brake rod in such a manner that on depressing the brake pedal the ends are drawn together and the shoes are pressed evenly to the brake drum. Two set screws are used to prevent the shoes from rubbing against the drum when the brake is off.

This form of brake belongs to the locomotive type. When the arms which are pivoted to the cross frame provide the brake surfaces, instead of the separate shoes, the brake is called a contracting band brake.

The essential requirements of any brake are: (1)

It must be reliable, (2) must be powerful enough to stop the car on a hill, (3) must be easy to put into action, (4) must keep cool, (5) must be able to prevent a car from forward and rearward movement, and (6) must not bind or grip.

Brakes of the contracting type do not fulfil condition (5).

For the rear-wheel brakes the expanding type is used. The internal surface of a drum bolted to the wheel is acted on by pivoted braking arms, AB, Fig. 87, which are opened out or expanded against the action of a spring S by a cam C which is actuated by levers from the side lever. Although the acting surfaces were usually metallic yet recent practice sees the use of prepared asbestos D on the arms, which has the advantage of a higher coefficient of friction. The position of the brake drums and actuating levers are also given in Figs. 90a and 91.

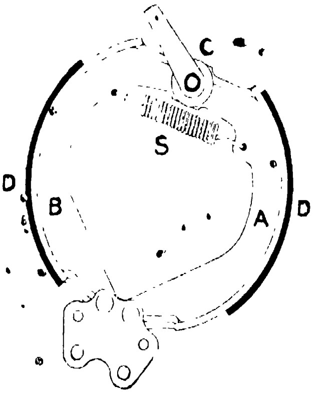


FIG. 87.—Expanding brake on rear wheels.

CHAPTER XVI.

THE BACK AXLE, CARDAN SHAFT, RADIUS RODS, TORQUE RODS, ETC.

THE back axle is in two parts which are mounted in a casing. The inner end of each shaft carries a bevel or spur pinion, and the outer ends are formed with dogs, keys or similar clutches to convey the drive to the road wheels.

A mechanism called the differential is used which enables the two shafts and road wheels to rotate at different speeds when the car is moving in a curved path. The two gear wheels on the inner ends of the shafts engage the opposite sides of similar gear or planet wheels which are free to revolve on their own spindles. These spindles are carried by a casing which is bolted to the bevel or worm wheel which takes the drive from a bevel or worm on the rear Cardan shaft. This shaft thus connects the rear axle to the gear box. The differential box revolves in ball or roller bearings in the main axle casing. When the car is proceeding in a straight line the box and gear wheels rotate solidly, but when the car is taking a curve, the planet wheels revolve in their axes so as to permit relative movement of the driving wheels.

Since the driven wheel on the differential is moving relatively to the main frame owing to its spring suspension, and the end of driving shaft which projects rearwardly from the gear box has no relative motion, allowance must be made for changes in length and inclination of the cardan or propeller shaft which connects them. In general, at the gear-box end is a universal joint and at the differential end is a plunging joint. The construction of a plunging universal joint is as follows and is illustrated in Fig. 88. At the end of the propeller shaft is a large hardened pin carrying a hardened steel block which is free to rotate upon the pin. The outer sides of the block are rounded, and slide in a couple of hardened parallel grooves formed in the forward tubular extension of the differential gear shaft. These grooves extend for a few inches, and the combination of pin, block, and grooves provides a universal joint that can slide to and fro.

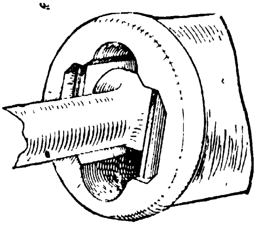


FIG. 88.

The student should plot a diagram of angular velocities of the cardan shaft for a selected inclination of the shaft as compared with the uniformly rotating gear shaft.

The universal joint should be housed in and be formed with efficient lubricating means.

In the form of differential shown in Fig. 89 bevel drive is employed and Timken bearings used throughout, the differential being at the centre of the back axle so that the two parts of the axle are equal in length and the load on the casing is equal. The driving bevel itself overhangs its forward bearing. A section is given of the female part of a plunging joint of the kind pictorially shown in Fig. 88.

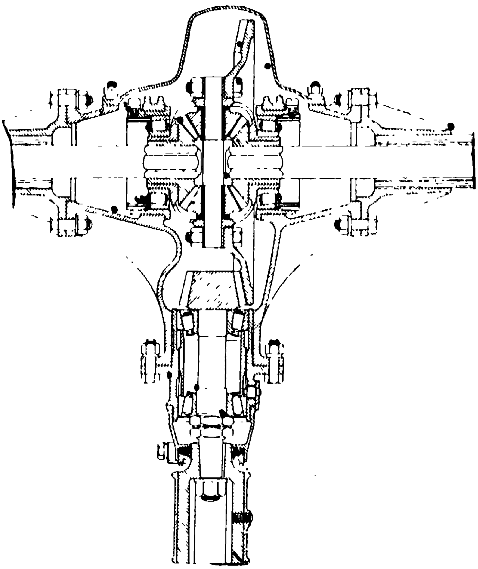


FIG. 89.—Differential gear.

By placing the differential out of the centre line, the bevel on the propeller shaft can be provided with an end bearing, but the casing is more complicated and the load is not equally distributed. A better construction is obtained as in Fig. 90, the driving bevel being suspended between two bearings. The differential in this case is made up with spur pinions.

When a worm drive is employed, the worm is easily provided with an end bearing and with the central differential. On the score of efficiency and silence there is now very little to choose between bevel and worm drives. The same applies to the cost of production of the two forms.

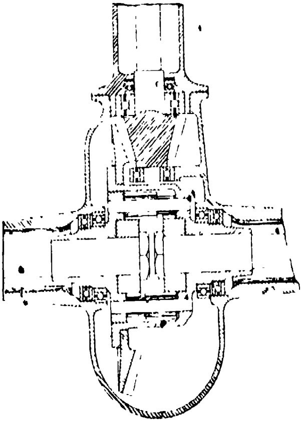


FIG. 90.—Spur differential.

Beside the ordinary parallel screw type of worm, the Hindley or Lanchester worm is used which is concave to correspond with the worm wheel whereby more length of thread is in engagement.

There are nearly as many kinds of axle casing as there are cars, but the tendency is towards the use of a central casing to which is bolted two pressed steel conical sleeves. The sleeves are formed with seatings for the springs, and the centre piece with an inspection door. Tie rods, as in Fig. 90*a*, or stiffening

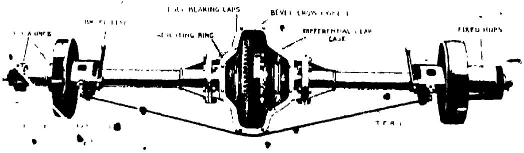


Fig. 90*a*.—Humber back axle.

flanges are sometimes used to cope with the vertical and horizontal bending moments on the casing.

If the wheels are mounted on the axle casing, Fig. 91, the driving shafts only transmit the power

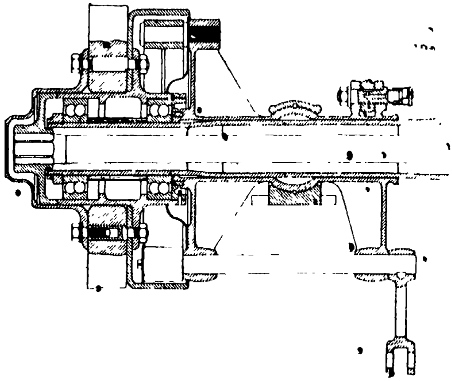


Fig. 91.—Wheel rotating on axle casing.

but do not support the load. The complete axle with this arrangement is said to be of the "full-floating type". This illustration also gives some idea of the method of mounting the brake drum and brake operating lever.

Radius Rods.—These are employed to maintain the back axle always at right angles to the main side frames under all conditions of springing and tractive effort, and for this purpose are usually fitted parallel to the side members and are attached to the axle casing at one end and to the side members or to one of the cross members. More often than not, the springs act as radius rods, being pivoted at one end to the frame.

Torque Rods.—The driving and braking strains upon the axle casing, although sometimes taken up by the springs, should be taken by rods or their equivalent designed for that purpose. In some cases the rods can effectively act in the dual capacity of torque and radius rods, a construction which allows this comprising a **V**-shaped frame pivoted to a cross member at the apex of the **V** and attached to the axle casing by **U** brackets.

In a form which is increasing in favour, the propeller shaft is enclosed in a tubular casing, the forward end of which is carried by the cross member upon which the rear end of the gear box is suspended. The centre of this universal-joint suspension should be in line with the main universal joint of the propeller if it is to function properly.

In another form which is light and effective, a **V** frame or "banjo" frame is placed in a vertical plane, the large end is attached to the axle casing at the top and bottom, and at the smaller end is a spring suspended from a cross member as in Fig. 92.

Chain Drive.—In a few commercial and in touring cars for the colonies and other countries where a high clearance is desirable, the differential and

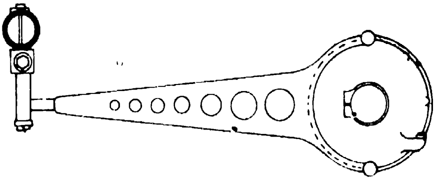


FIG. 92.—"Banjo" torque member.

cross shafts are mounted in the gear box, the outer ends of the shafts having sprockets which drive by chain to sprockets on the road wheels.

CHAPTER XVII.

STEAM CARS.

An examination of the chassis of a steam car reveals quite clearly the essential differences between it and the chassis of a car fitted with a petrol engine. The additions comprise a water tank, a water pump, a steam generator, and a fuel pump. The parts which do not appear are the magneto, the carburetter, the clutch, gear box and sometimes the cardan shaft. The frame, front axle, steering gear and back axle are practically common to both types of car.

The steam engine has been neatly described as an external combustion engine, it is consequently necessary for us to deal with the engine and the external mechanism producing the power gases, viz., the steam generator. Steam is produced from water by heating it to such a temperature that it vaporizes, the temperature being dependent upon the superposed pressure. Under atmospheric pressure such as is the case with water in a kettle, this temperature is 212° Fahr., under 100 lb. of pressure 328° Fahr., and for 200 lb., 380° Fahr. A complete table of pressures and temperatures is given in the Appendix. If the steam is further or simultaneously heated to a higher temperature and the pressure is maintained, the steam is said to be *superheated.*

Superheated steam is a perfect gas and obeys the known laws of gases, it can therefore be depended upon to realize its calculated powers.

Steam Generators.—There are three main types of generators or boilers :—

1. Fire tube.
2. Water tube.
3. Flash or semi-flash.

In *Fire Tube* boilers, the water is contained in a tank fitted internally with tubes through which pass the heating gases. This type is only used in commercial wagons of the tractor type and then only to a very limited extent.

In *Water Tube* boilers the water circulates inside the tubes and the heating gases surround the outside, the tubes always containing some water. Auxiliary fittings comprise a *feed-water heater*, that is a vessel in which the water before it enters the boiler is warmed by live or exhaust steam or by the waste heating gases. In addition to that a *superheater* may be used, that is a vessel into which is passed the steam generated in the main boiler and which is placed in the path of the heating gases where the temperature is highest. The steam in the superheater is in free communication with that in the boiler, so that the pressure is the same.

Flash generators are really a particular case of water-tube boilers, in which the tubes serve not only for the production of steam but simultaneously act as superheaters. This type of generator is the one most commonly found on touring cars. In order that this double function of the tubes may occur, the water is fed to the tubes which are red-hot in small quantities where it is immediately converted into steam and superheated. The tubes at the same time lose heat and get dull and the steam passes to the engine. By the time the next charge of water is forced into the tubes the latter have been warmed to their red-hot state.

In flash boilers as used on motor cars, solid cold-drawn steel tubing capable of standing a pressure of 6000 lb. per square inch is formed into flat coils, a number of such flat coils or sections being placed one above the other, coupled together, and placed in a casing or shell. By using these sections renewals can be easily and cheaply effected. Water is supplied to the boiler either by a power-driven pump or by compressed air, a small air pump driven off the main engine being used in the latter case. A hand-operated water pump is fitted so that the initial supply can be obtained before the engine is started.

The heating means comprise a burner situated at the bottom of the casing and having a large number of holes therein, from which the vaporized fuel issues and at which it is burnt. The paraffin or petrol is supplied to the burner in adjustable quantities, the adjustment being effected by a hand lever. This means that the quantity of heat produced and therefore that the amount of steam generated are in consequence under the direct control of the driver.

It passes to the burner via a vaporizing coil tube, that is a warm tube in which a preliminary heating of the fuel takes place with the object of properly vaporizing it. In connexion with the vaporizer there is an induction tube, through which the necessary air is drawn, and where the air is also subjected to a preliminary heating.

When first lighting up, this vaporizing coil is warmed by a small bunsen which is cut out of use as soon as the main burner is sufficiently warm.

A small burner with its own air supply is fitted, and is known as the "pilot light". Its function is to maintain the pressure when the car is idle and no steam is being used; it has to supply enough heat to balance the losses by radiation from the boiler and its fittings.

A generator of the fire-tube type, and as made for car work, comprises a steel shell which is bound with steel wire under tension and to which top and bottom plates are welded. The upper and lower plates are drilled to take half-inch flue tubes, about five hundred tubes with a heating surface of approximately seventy square feet being required for a ten-horse-power set. The burner is of the type wherein the vaporized fuel issues from a large number of orifices, and in which a small supplementary pilot flame serves as a stand-by when the car is stationary. As far as possible all the controls are automatic in action, three being the usual number provided.

These are: (1) An automatic valve which cuts off the supply of fuel to the main burner when the steam pressure reaches a certain pre-determined value, normally about 600 lb. per square inch; (2) a safety valve which opens at about 700 lb.; and (3) a fusible plug which is fitted in the boiler shell and melts when the level of water gets too low, owing to the temperature of the generator shell rising above the fusion point of the plug. The escaping steam acts as a warning.

In one form of apparatus the automatic control of the fuel valve is obtained by mounting it so that the needle valve or valve spindle is coupled to or rests on a copper diaphragm. Steam is led to the space above the diaphragm and a small spiral spring is fitted beneath it, the diaphragm thus moves up or down as the steam pressure falls below or rises above that due to the spring and carries with it the valve.

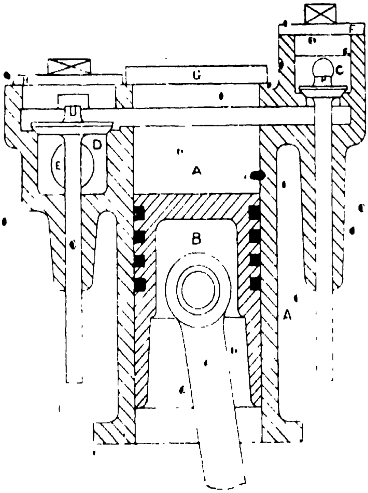


FIG. 93.—Simple single-acting steam engine.

The water is carried to the boiler by pumps, a by-pass being fitted between the pumps and the generator, the valve of which is under the control of the driver.

The gauge glass which indicates the height of water in the boiler is placed in sight of the driver who closes the by-pass or opens it according to whether the boiler is in need of water or not, that is when the level is low or high. The steam generated passes to a coil of tubing at the bottom of the generator and immediately above the main burner where it becomes superheated before passing to the engine.

The Engine.—Before discussing the types of engines, it will be useful to consider the action of steam in the simplest type and to study the indicator diagram thereof. Imagine a single cylinder A, Fig. 93, with a piston B and an admission valve C and exhaust valve D. Suppose the piston B to be at the inner dead centre, high pressure steam is admitted through the valve C. When the piston has moved $\frac{1}{r}$th of its stroke, steam is "cut off" by closing the valve C, and for the rest of the stroke the steam already in the cylinder expands and acts with diminishing pressure upon the piston. The expansion follows the law $P . V^n = C$, where P is the pressure and V is the volume of the steam and the constant n is unity. Just before the end of the stroke, the pressure is released by opening the valve D, the exhaust pipe E communicating direct with the atmosphere or with a condenser. The piston now moves back and expels the steam which remains approximately at atmospheric pressure or the pressure in the condenser, until about $\frac{8}{10}$ of the stroke has been performed when the valve D is closed and the remaining steam is compressed.

The diagram for such a single-acting engine is shown in Fig. 94, the dotted line representing the atmospheric line, A and B being the ends of the stroke and C the position of the cut-off.

OA is a measure of the free space above the piston when at its inner centre.

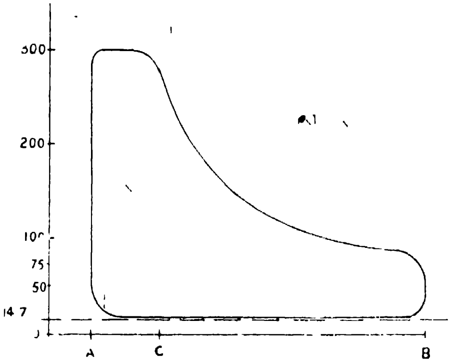


FIG. 94.—Theoretical indicator diagram for single-acting non-condensing steam engine.

The ratio of the volume OB to the volume OC is known as the ratio of expansion, the diagram is plotted for a maximum pressure of 300 lb. per square inch absolute, that is 300 - 14·7 = 285·3 lb. by gauge. When corrected for inertia and a crank effort diagram is plotted, the evenness of the torque as compared with that obtained from a petrol engine of like power is most marked.

Where this single-acting type of engine has been used, three cylinders are provided, the pistons of which act on cranks at 120°. The valves are of the mushroom or poppet type and are actuated by cams similar to those in the ordinary petrol engines. In this case, the position at which the steam is cut off, commonly called The Cut-off, may be varied by sliding the cam on its shaft, the cam surface being of a suitable profile. Valve caps, H, F, and a screwed plug acting as a cylinder cover G are generally used as in Fig. 93.

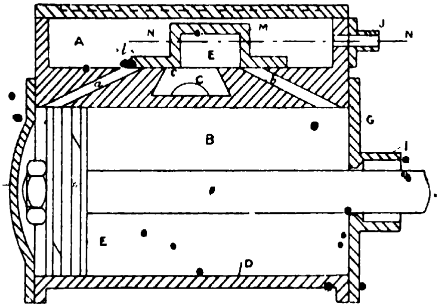


FIG. 95.—Double-acting steam engine.

A second class of car engine which is used approximates to the normal type of steam engine. By closing both ends of the cylinder and supplying steam thereto the engine becomes double acting. The valves employed are of two kinds, one form is that known as the D-shaped such as is shown at M in Fig. 95, the complete drawing representing a double-acting engine. The cylinder has two covers H G, the latter having a stuffing box I through which the rod F of the piston E passes. The end of the rod outside the cylinder is connected to a cross-head which is in turn coupled to the crank by a connecting rod. A stuffing box J is also provided on the valve or steam chest A through which the valve rod (the position of which is indicated by a dotted NN line) passes. The rod is connected by an eccentric rod with the strap of an eccentric on the main crank shaft.

Some idea of how a D-valve controls the passage of steam from the valve chest A to the cylinder B and from the cylinder to the exhaust C should now be obtained. We will first consider what is happening in the left-hand part of the cylinder. With the piston at its inner dead centre and the valve in the position shown, steam is able to get into the cylinder by the port *a*. The corresponding position for the eccentric is as shown in Fig. 96. The angle MON is known as the "Angle of Advance," and the distance between the centre of the crank shaft and the centre P of the eccentric is the "Virtual crank radius" of the eccentric—equal to the half travel of the valve.

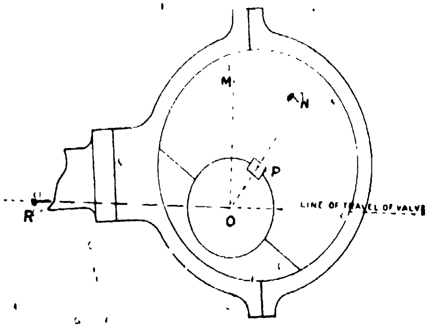


Fig. 96.—Eccentric sheave and strap.

The dotted line OR represents the position of the main crank. The amount of port opening *l* is called the "lead" of the valve. As the piston moves to the right, the valve also moves to the right, reaches its extreme right position and then returns until the port *a* is covered and the steam is cut off. The valve continues to move to the left and the piston to the right, until eventually the port *a* and exhaust *c* are in communication with each other via the hollow part E of the valve—this, the position of "release," occurs just before the end of the stroke. During the major portion of the return stroke, the ports *a*, *c*, are

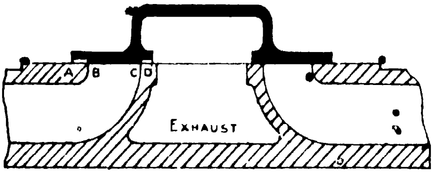


FIG. 97.—Valve in mid position.

connected, the valve having travelled to its extreme left position and returned some distance on its movement to the right. Just before the end of the exhaust stroke the valve shuts off the port *a* from the exhaust, and the steam remaining in the cylinder is compressed to act as a "cushion" to the piston. Practically at about 15° of crank angle before the inner dead centre, the port is opened to steam and the cycle of operations starts over again. The same cycle is taking place on the outer end of the cylinder as the valve controls the steam port *b* in the same manner as it does the port *a* but with a "phase" difference, that is it is half a revolution behind the inner end.

The valve in its mid position overlaps the steam and exhaust ports by amounts *ab*, *cd*, Fig. 97, which are known respectively as the "outside lap" and "inside lap".

Another type of valve which is sometimes used is the Piston Valve of which one form is shown in Fig. 98. The two end parts A, B act as controls of the ports leading to the cylinder. These ports extend as annular passages around the inner surface of the cylindrical steam chest. The valve rod is attached to the boss C which is carried by three or four webs from the walls of the valve.

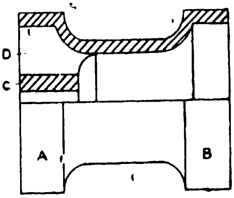


Fig. 98.—Piston valve.

The ordinary method of actuating these valves consists in employing an eccentric and link motion such as is illustrated in Fig. 99. When the link *ab* is in the position shown, the valve which is coupled by the rod C to a block *e* moves as though coupled to the eccentric A and the valve is set for forward running. If the link is thrown over by the rod E so that the part *b* is in line with the valve rod C, then the eccentric B is alone actuating the valve and the eccentric A is idly moving the end *a* of the link. At the same time the valve will be placed in a new position relative to the piston and the crank shaft will be rotated in the opposite direction for reverse running. When the link is in the mid position, the two eccentrics neutralize one another for the ends *ab* will be moved equally and in opposite directions, consequently the block *c* which is at the centre does not receive any motion. Under these circumstances even with the throttle valve full open no movement of the shaft takes place. Intermediate positions of the link vary the resultant effect of the eccentrics upon the valve over a range from full power ahead to full astern.

Where the complete expansion cannot be conveniently utilized in one cylinder, two or more may be used, the exhaust of the H.P. (high pressure) cylinder being admitted to the L.P. (low pressure) cylinder to complete its expansion. On one engine of this type, a valve is fitted which enables the L.P. cylinder to act as a H.P. cylinder under circumstances in which more power is required than normal, as when starting a car or when going up hill.

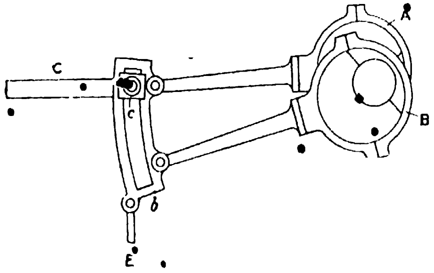


Fig. 99.—Link motion.

The power obtainable from a steam engine can be regulated by the quantity and pressure of steam generated, and the engine can be stopped or started it will, so that a clutch and gear box are not necessary on a steam car. As compared with a petrol car the weight of the steam generator is balanced by the absence of these other parts.

In contradistinction to the petrol engine which has to be enclosed in a heat-extracting medium, the cylinder of a steam engine has to be lagged with asbestos or the like which prevents heat from radiating away.

A splendid arrangement of the engine on the chassis which gives high efficiency, consists in coupling the crank shaft direct to the main spur pinion of the differential, any relative movement of the engine and chassis which it is necessary to provide for being obtained by mounting the engine on a frame which at one end is attached to the back axle casing and at the other is hung by straps or other flexible suspension from the chassis.

CHAPTER XVIII.

OTHER TRANSMISSION SYSTEMS.

Friction Drive.—This system differs from the usual one in that the clutch and change speed gear are replaced by a single mechanism. Cheapness in first cost is the main advantage. Its disadvantages are that a positive drive is not always obtainable and slip when it does occur appears just when it is not wanted.

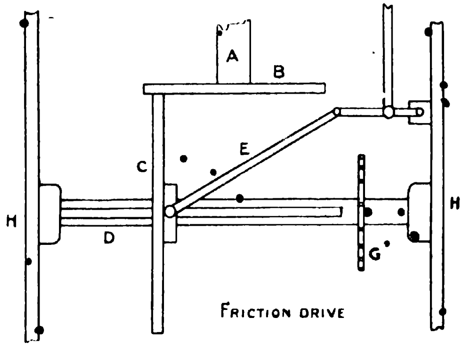


FIG. 100.

A diagrammatic view of a friction drive gear is shown in Fig. 100 in which the engine shaft A carries a disk B. A cross shaft D, mounted either rigidly in the side frames H or slidably under the action of springs, has keyed to it a disk C, which contacts with the engine disk B and can be moved by levers E, F. The shaft D also carries a sprocket wheel G whence a chain takes the drive to a sprocket on the differential.

Let N be the number of revolutions per minute of the shaft A,

and n be the number of revolutions per minute of the shaft D,

also D be the diameter of the disk C in feet,

and d the distance in feet of the point of contact of the disks from the axis of the shaft A.

Then $\pi \,.\, D \,.\, \left(\frac{n}{60}\right)$ = velocity in feet per second of the rim of the disk C,

and $\pi \,.\, d \,.\, \left(\frac{N}{60}\right)$ = velocity in feet per second of the circle of contact on B.

If there is no slip,

$$\text{Then } \pi \,.\, D \,.\, \left(\frac{n}{60}\right) = \pi \,.\, d \left(\frac{N}{60}\right)$$

$$\text{or } D \,.\, n = d \,.\, N.$$

It follows therefore, and taking D and N as constants, that as the disk C is moved along its shaft so that d varies from zero to a maximum, then its rate of revolution increases proportionately from zero to a maximum.

When the torque, T lb. feet of the engine shaft is constant, the pressure at the contact circle varies inversely with the distance D, and in general terms equals p such that $p \,.\, d = T$.

In order that this torque shall be fully transmitted to the disk C, the latter must be pressed against the disk B, by a pressure P lb. $= \mu . p = \mu . \frac{T}{d}$ where μ is the coefficient of friction for the two surfaces. P must therefore be greatest when d is smallest and when n is smallest, i.e., when the car is climbing a hill or being started up. The attempts to regulate the pressure P as required in the above manner have resulted in complicated mechanisms which do away with the simplicity of the system. Further, these attempts have not been brought to a successful issue.

Another point which arises from the thickness of the disk C is that, although all points on its periphery have a constant speed for any given position of the disk, yet the inner and outer circles of contact have different speeds, so that there must be some slip and consequent wear, which necessitates renewals, and perpetual adjustment of the levers and shafts keeping the disks in contact.

Hydraulic Transmissions.—Replacing the clutch, gear box, cardan shaft (or chain and sprockets) and also the differential, this system cannot be passed by without comment. Apparatus similar to that proposed for cars has already been successfully employed in other engineering spheres; and now is beginning to make its mark in a practical way in Motor Car Engineering.

The Manly System is being fitted to commercial vehicles in the United States, the Charron Motor Company have run one of their gears 30,000 miles, and showed a chassis fitted with it at the Olympia, 1912, and the Hele-Shaw-Leigh-Martineau system has given satisfaction on the cars so fitted, Briefly the apparatus includes a pump driven by an internal combustion engine and supplying liquid under pressure to liquid pressure engines which drive the cross shafts of the driving wheels. The liquid used is generally oil, and the variations in speeds and neutral are obtained by one or two control rods. In all the successful forms the torque transmitted has been maintained practically constant.

Tests made show on an average an efficiency of 85 per cent or thereabouts, the variables being: (1) the size of the apparatus; (2) the ratio of the number of revolutions of the prime mover to the number of revolutions of the driven shafts; and (3) the load. It has been found that under continuous load the temperature of the oil does not rise above about 150° Fahr.

The gear fitted to Charron cars is that invented and designed by Dr. Lentz, a diagram being given in Fig. 101.

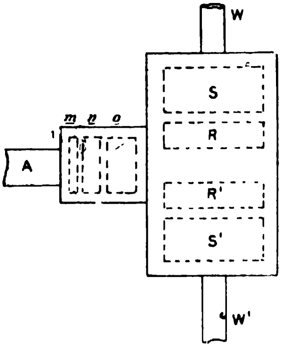


Fig. 101.—Lentz hydraulic system.

Situated in the position ordinarily occupied by the differential casing, is a casting bored to take three rotary sliding-vane pumps *m*, *n*, *o*, of different capacities and two sets of rotary engines *R*, *S*, and R^1, S^1. The pumps are driven by the shaft A which is coupled to the engine shaft, and the engines R, S, R^1, S^1, drive the wheel shafts W, W^1 respectively.

In the neutral position a valve is opened which by-passes the delivery from the pumps back to the suction side, consequently the engines R, S, R^1, S^1, do not rotate and the car remains stationary. When the by-pass valve is closed, further power, speed and braking control is obtained by cutting out one or two of the pumps or one or other of the engines from the oil circuit. The engines R and R^1 are supplied in common from the pumps, as are also the engines S and S^1 with the result that a differential action is automatically set up should one road wheel encounter a greater resistance than the other.

Just as an example of control assume the capacities of the engines R, R^1 to be half of the capacities of the engines S, S^1 respectively, and that the total capacities of the four engines R, R^1 and S, S^1 equal $\frac{1}{12}$ the total capacity of the pumps *m*, *n*, *o*.

Suppose all the pumps feeding all the engines. Then since the capacities are as 1 : 12 the revolutions of the shaft A to shafts W, W^1 will be as 1 : 12. Now suppose the engines R, R^1 cut out, the capacities of pumps to engines will be as $\frac{2}{3}$: 12 and the revolutions as 18 : 1. Or again if the capacities of the pumps *m*, *n*, *o*, are $\frac{1}{6}$, $\frac{1}{3}$, and $\frac{1}{2}$ of their total, then with the pump *n* feeding all the engines the capacity ratio is 1 : $\frac{1}{3}$ (12), as 1 : 4 and the velocity ratio 4 : 1.

Using oil as the power-liquid tends to diminish wear of the parts. The difficulty of keeping the glands tight is considerable, owing to the high liquid pressures reached and has been in some measure the reason for these gears not being commercialized earlier.

In the Hele-Shaw-Martineau and also Manly gears the control consists in varying the stroke of the pumps and so their capacity. Usually the pumps and engines are of the radial type, but in one form of the Hele-Shaw the pumps are parallel to the shaft and the plungers are driven by a swash-plate mechanism.

By varying the inclination of this plate to the shaft the stroke of the pumps is varied.

Hydraulic transmission gears are certainly worthy of more attention than is at present bestowed upon them.

Petrol Electric System.—The petrol motor in this system is coupled to a machine which is capable of acting as a dynamo or motor according to requirements.

Accumulators are carried which supply extra power when needed, and they may be used for starting. They are charged during the time that the power required for propulsion is lower than the maximum power of the petrol engine, such as when the car is going up hill.

Electric Transmission.—The power is in this case wholly supplied by a petrol engine which drives a dynamo the current from which goes to motors placed on the shafts of the driving wheels. Accumulators may or may not be used in addition.

Complete Electric Installation.—In this system, accumulators form the source of power, from which it is taken by electric motors. The batteries are charged at a power station when necessary. In this connexion it would appear that the alkaline type of accumulator will be of great value, since it can be so rapidly charged without injury.

The restricted radius of action has been against the electric vehicle, but with the power to run for say six hours and then be able to re-charge in one hour, and also because the alkaline form provides a battery of greater capacity for a given weight, the electric car should gradually come into favour.

With more electric cars on the road it will be possible to arrange with power stations for a system of interchangeable units, the recharging can then be performed at the convenience of the engineer when his load is light and the car-owner can proceed without waste of time.

The simplicity of control and the reliability of electric motors is all in favour of the electric car.

THE END

APPENDIX.

CITY AND GUILDS SYLLABUS IN MOTOR CAR ENGINEERING.

ORDINARY GRADE.

PETROL CAR.—*Engines.*—General construction of Internal Combustion Engines. The Otto Cycle. Two-stroke Cycle. Particular construction of a Petrol Motor Engine. Details of joints. The water circulation.

Petrol.—Source, distillation, density, and calorific value.

Carburation.—Explosive mixture of petrol vapour and air. Compression, and its effect on explosive mixture.

Horse-power of Petrol Motors. Difficulty of measuring indicated horse-power accurately. Brake horse-power. Mechanical efficiency. Theoretical indicator diagram of a Petrol Motor. General explanation of the terms adiabatic and isothermal expansion; adiabatic and isothermal compression. Firing by compression. Limits of compression ratio. Balancing and torque crank effort diagrams.

Tractive Force.—General considerations of road, side-slip, wind resistance, and gradients.

Carburetters.—General principle of the action of a Carburetter and description of the various forms in use.

Speed Gears.—Sliding gear, epicyclic, variable speed gears, chain and belt change speeds, hydraulic transmission.

Steering Gear.—General descriptions of.

Clutches.—Cone, slipping disk, Hele-Shaw, Jenatsy.

Cooling.—Air cooling, water cooling, radiators, circulating pumps, order of circulation.

Lubrication.—Methods of lubrication and appropriate lubricants.

Readjustments.—Grinding and setting valves, timing ignition, testing for faults in ignition system.

Transmission. Chain drive, live-axle, tilt or lift of "Cardan" shaft.

Chassis.—Wheel base, forms of car frames, underframes, springs and brakes.

ELECTRIC IGNITION.—Primary Batteries and Small Accumulators used in connexion with Ignition Apparatus.

Ignition.—High and low tension sparks, effect of pressure on spark-gap.

Electro-Magnetic Induction.—Brief explanation.

Induction Coil.—Construction of trembler and non-trembler coils and theory of working. ("Lodge coil" and B spark.)

Wiring.—Of one or more cylinders, high and low tension distribution. (Note: Students should be encouraged to use coloured pencils when drawing diagrams of coils, magnetos and ignition systems; say, red for low tension leads, blue or green for high, and black for constructional parts.)

Magneto-Ignition.—General description of method and apparatus.

STEAM CARS.—*Engines.*—General description of ordinary types.

Steam Generators.—Multitubular, flash and semi-flash boilers.

Burners and Fuels.—Coke, crude petroleum, paraffin, petroleum spirit. Calorific values. Construction of burners suitable for liquid fuel.

Boiler Feed-Pumps.—Gear driven, steam driven, and auxiliary hand pumps, with their connexions and injectors.

Automatic Systems.—Automatic regulation of feed water and fuel.

Condensers.—General description of condensers and the object of their use.

ELECTRIC CARRIAGES.—*Lead Accumulators.*—Construction of plates for various makes of cells, chemical changes which take place, connecting up cells, duration of charges, current per square foot of plate, densities of acid, efficiencies of batteries actual, and theoretically possible, energy capacity per unit weight of plate, how to tell when battery is charged and how to ascertain the remaining charge. General description of various types of batteries.

Motors.—Series, Shunt.

Controllers.—Various methods of control. Electric brakes, impracticability of re-charging cells when descending hills.

Transmission.—Helical gear, etc., use of two motors to avoid differential.

Cut-outs.—Quick-break pedal switches, fuses.

GARAGE SYSTEMS.—For housing and tending electric carriages, cost of running, weight of vehicle, speed, care required, radius of action, removing and replacing batteries.

Advantages and disadvantages of electric compared with internal combustion motors.

MOTAR CAR ENGINEERING EXAMINATION PAPER.

1. Show a complete wiring diagram for an ordinary four-cylinder vertical engine fitted with duplicate ignition (battery and H.T. magneto). If possible, use different coloured pencils or inks for wires carrying high and low tension currents. (48 *marks.*)

2. A single-cylinder car with the engine under the body has about 7 feet of H.T. lead from the plug to the coil on the dash. If the insulation of this wire

gradually perishes, what are the first symptoms you expect? Describe how, when these symptoms are observed, you would proceed to locate the fault exactly, and prove it to be due to a leak in the H.T. wire and nothing else. What other defects would give similar symptoms? (42.)

3. Given a new 4-volt ignition accumulator or lead secondary battery (without any printed instructions) to fill with acid and charge for use, state what acid you would use, how you would dilute it, and to what density. If you find there are two negative plates and one positive plate each measuring 5 inches by 4 inches in each cell, what charging current would you give, and for how long? (42.)

4. Sketch carefully a section of a well-designed cheap piston, showing rings, gudgeon, small end of connecting rod and bush. Indicate with arrows the materials of which the parts are constructed. (42.)

5. A car fitted with live axle and two universal joints in the propeller drive has a torque rod 4 feet long to prevent the axle case from rotating; the car weighs 1 ton, and is climbing a hill of 1 in 7. Calculate the force (due to gradient only, neglecting road resistance, etc.) which the forward end of the torque rod exerts on its support. Tyres 810 by 90 (25·4 mm. = 1 inch). (42.)

6. Draw a modern locomotive type foot brake suitable for the car described in question 5. Show method of adjustment and means for preventing rubbing and rattling. (42.)

7. Represent the motion of the crank pin by a circle about 3 inches diameter, and indicate the direction of rotation with an arrow. Mark on this circle, for an ordinary four-stroke cycle engine, the dead centres and the positions of the crank pin when the inlet and exhaust valves should open and close, and when the magneto spark should occur for fully advanced and retarded ignition. Give the angle in degrees of each point from the nearest dead centre. (42.)

8. Carefully draw two curves indicating the relation between pressure and volume when the engine piston is on its compression stroke. One curve should show the rise in pressure when the engine is pulled over compression very slowly by hand (isothermal compression); the second curve should represent the result of sudden compression (adiabatic). Insert a few figures of pressures and volumes if possible. (42.)

9. Sketch two kinds of boilers in use on steam motor road vehicles. Give the working pressures and blow-off pressures and approximate diameters and lengths of boiler tubes in each case. Name a manufacturer of each type. (42.)

ORDINARY GRADE.

All candidates must attempt Questions 1 *and* 2 *and not more than five others.*

1. Describe briefly the construction of any small car with which you may be familiar; taking each organ in turn, giving its situation and the type to which it belongs, also noting any special or good features. (50 *marks.*)

2. Supposing the ignition gear in the car described in Question 1 to be in perfect working order but that you cannot get the engine to start, how would you systematically set about to *locate* the fault before attempting to put it right or to alter any adjustments? (40.)

3. Sketch, in section, a good design of clutch and fly-wheel, showing the clutch pedal. State briefly what are its good features. (40.)

4. What horse-power is required to move a motor delivery van, weighing 3½ tons, at 12 miles per hour along a level road, the necessary tractive force to overcome road resistance being 45 lb. per ton? (40.)

5. State precisely what materials are generally used for constructing the following car parts:—Engine cylinders, crank shaft, balls in the ball bearings, core or centre part of magneto armature, ordinary sparking plug points. What is the white metal made of which is commonly used for lining big end bearings? (40.)

6. Answer *either* of the following:—

(*a*) Suppose you have a 3-ampère hour 4-volt accumulator to be recharged, show in a diagram the necessary connexions and apparatus for recharging, using any source of current supply you like. State what current you would give, for how long you would charge and how you would regulate the current.

or

(*b*) Draw just a line diagram showing the wiring for a non-trembler coil ignition system, for a motor cycle with a 4-volt battery.

If the coil takes 3 ampères, what is its resistance in ohms? (40.)

7. Show the construction of a trembler ignition coil by a sketch, taking care to make the connexions quite clear, preferably with coloured pencils or inks, stating which terminal has to be connected to the sparking plug and which to the battery, etc. (50.)

8. Represent, diagrammatically, a low-tension magneto, and show the connexions to a 4-cylinder engine. Show the make and break mechanism for one of the cylinders, and state the relative speed of the armature to the crank shaft. (40.)

9. Sketch a liquid fuel burner, and show the tank and necessary pipe connexions, etc., for a steam car. State the fuel used and how it is forced to the burner. (40.)

10. What are the chief necessary electrical parts in an electric carriage? Why are electric cars not more commonly used for country work? (40.)

TABLES.

LOGARITHMS.

	0	1	2	3	4	5	6	7	8	9	1	2	3	4	5	6	7	8	9
10	0000	0043	0086	0128	0170						4	9	13	17	21	26	30	34	38
						0212	0253	0294	0334	0374	4	8	12	16	20	24	28	32	37
11	0414	0453	0492	0531	0569						4	8	12	15	19	23	27	31	35
						0607	0645	0682	0719	0755	4	7	11	15	19	22	26	30	33
12	0792	0828	0864	0899	0934	0969					3	7	11	14	18	21	25	28	32
							1004	1038	1072	1106	3	7	10	14	17	20	24	27	31
13	1139	1173	1206	1239	1271						3	7	10	13	16	20	23	26	30
						1303	1335	1367	1399	1430	3	7	10	12	16	19	22	25	29
14	1461	1492	1523	1553							3	6	9	12	15	18	21	24	28
					1584	1614	1644	1673	1703	1732	3	6	9	12	15	17	20	23	26
15	1761	1790	1818	1847	1875	1903					3	6	9	11	14	17	20	23	26
							1931	1959	1987	2014	3	5	8	11	14	16	19	22	25
16	2041	2068	2095	2122	2148						3	5	8	11	14	16	19	22	24
						2175	2201	2227	2253	2279	3	5	8	10	13	15	18	21	23
17	2304	2330	2355	2380	2405	2430					3	5	8	10	13	15	18	20	23
							2455	2480	2504	2529	2	5	7	10	12	15	17	19	22
18	2553	2577	2601	2625	2648						2	5	7	9	12	14	16	19	21
						2672	2695	2718	2742	2765	2	5	7	9	11	14	16	18	21
19	2788	2810	2833	2856	2878						2	4	7	9	11	13	16	18	20
						2900	2923	2945	2967	2989	2	4	6	8	11	13	15	17	19
20	3010	3032	3054	3075	3096	3118	3139	3160	3181	3201	2	4	6	8	11	13	15	17	19
21	3222	3243	3263	3284	3304	3324	3345	3365	3385	3404	2	4	6	8	10	12	14	16	18
22	3424	3444	3464	3483	3502	3522	3541	3560	3579	3598	2	4	6	8	10	12	14	15	17
23	3617	3636	3655	3674	3692	3711	3729	3747	3766	3784	2	4	6	7	9	11	13	15	17
24	3802	3820	3838	3856	3874	3892	3909	3927	3945	3962	2	4	5	7	9	11	12	14	16

25	3979	3997	4014	4031	4048	4065	4082	4099	4116	4133	2	3	5	7	9	10	12	14	15
26	4150	4166	4183	4200	4216	4232	4249	4265	4281	4298	2	3	5	7	8	10	11	13	15
27	4314	4330	4346	4362	4378	4393	4409	4425	4440	4456	2	3	5	6	8	9	11	13	14
28	4472	4487	4502	4518	4533	4548	4564	4579	4594	4609	2	3	5	6	8	9	11	12	14
29	4624	4639	4654	4669	4683	4698	4713	4728	4742	4757	1	3	4	6	7	9	10	12	13
30	4771	4786	4800	4814	4829	4843	4857	4871	4886	4900	1	3	4	6	7	9	10	12	13
31	4914	4928	4942	4955	4969	4983	4997	5011	5024	5038	1	3	4	6	7	8	10	11	12
32	5051	5065	5079	5092	5105	5119	5132	5145	5159	5172	1	3	4	5	7	8	9	11	12
33	5185	5198	5211	5224	5237	5250	5263	5276	5289	5302	1	3	4	5	6	8	9	10	12
34	5315	5328	5340	5353	5366	5378	5391	5403	5416	5428	1	3	4	5	6	8	9	10	11
35	5441	5453	5465	5478	5490	5502	5514	5527	5539	5551	1	2	4	5	6	7	9	10	11
36	5563	5575	5587	5599	5611	5623	5635	5647	5658	5670	1	2	4	5	6	7	8	10	11
37	5682	5694	5705	5717	5729	5740	5752	5763	5775	5786	1	2	3	5	6	7	8	9	10
38	5798	5809	5821	5832	5843	5855	5866	5877	5888	5899	1	2	3	5	6	7	8	9	10
39	5911	5922	5933	5944	5955	5966	5977	5988	5999	6010	1	2	3	4	5	7	8	9	10
40	6021	6031	6042	6053	6064	6075	6085	6096	6107	6117	1	2	3	4	5	6	8	9	10
41	6128	6138	6149	6160	6170	6180	6191	6201	6212	6222	1	2	3	4	5	6	7	8	9
42	6232	6243	6253	6263	6274	6284	6294	6304	6314	6325	1	2	3	4	5	6	7	8	9
43	6335	6345	6355	6365	6375	6385	6395	6405	6415	6425	1	2	3	4	5	6	7	8	9
44	6435	6444	6454	6464	6474	6484	6493	6503	6513	6522	1	2	3	4	5	6	7	8	9
45	6532	6542	6551	6561	6571	6580	6590	6599	6609	6618	1	2	3	4	5	6	7	8	9
46	6628	6637	6646	6656	6665	6675	6684	6693	6702	6712	1	2	3	4	5	6	7	7	8
47	6721	6730	6739	6749	6758	6767	6776	6785	6794	6803	1	2	3	4	5	5	6	7	8
48	6812	6821	6830	6839	6848	6857	6866	6875	6884	6893	1	2	3	4	4	5	6	7	8
49	6902	6911	6920	6928	6937	6946	6955	6964	6972	6981	1	2	3	4	4	5	6	7	8
50	6990	6998	7007	7016	7024	7033	7042	7050	7059	7067	1	2	3	3	4	5	6	7	8

LOGARITHMS.—*Continued.*

	0	1	2	3	4	5	6	7	8	9	1	2	3	4	5	6	7	8	9
51	7076	7084	7093	7101	7110	7118	7126	7135	7143	7152	1	2	3	3	4	5	6	7	8
52	7160	7168	7177	7185	7193	7202	7210	7218	7226	7235	1	2	2	3	4	5	6	7	7
53	7243	7251	7259	7267	7275	7284	7292	7300	7308	7316	1	2	2	3	4	5	6	6	7
54	7324	7332	7340	7348	7356	7364	7372	7380	7388	7396	1	2	2	3	4	5	6	6	7
55	7404	7412	7419	7427	7435	7443	7451	7459	7466	7474	1	2	2	3	4	5	5	6	7
56	7482	7490	7497	7505	7513	7520	7528	7536	7543	7551	1	2	2	3	4	5	5	6	7
57	7559	7566	7574	7582	7589	7597	7604	7612	7619	7627	1	2	2	3	4	5	5	6	7
58	7634	7642	7649	7657	7664	7672	7679	7686	7694	7701	1	1	2	3	4	4	5	6	7
59	7709	7716	7723	7731	7738	7745	7752	7760	7767	7774	1	1	2	3	4	4	5	6	7
60	7782	7789	7796	7803	7810	7818	7825	7832	7839	7846	1	1	2	3	4	4	5	6	6
61	7853	7860	7868	7875	7882	7889	7896	7903	7910	7917	1	1	2	3	4	4	5	6	6
62	7924	7931	7938	7945	7952	7959	7966	7973	7980	7987	1	1	2	3	3	4	5	6	6
63	7993	8000	8007	8014	8021	8028	8035	8041	8048	8055	1	1	2	3	3	4	5	5	6
64	8062	8069	8075	8082	8089	8096	8102	8109	8116	8122	1	1	2	3	3	4	5	5	6
65	8129	8136	8142	8149	8156	8162	8169	8176	8182	8189	1	1	2	3	3	4	5	5	6
66	8195	8202	8209	8215	8222	8228	8235	8241	8248	8254	1	1	2	3	3	4	5	5	6
67	8261	8267	8274	8280	8287	8293	8299	8306	8312	8319	1	1	2	3	3	4	5	5	6
68	8325	8331	8338	8344	8351	8357	8363	8370	8376	8382	1	1	2	3	3	4	4	5	6
69	8388	8395	8401	8407	8414	8420	8426	8432	8439	8445	1	1	2	2	3	4	4	5	6
70	8451	8457	8463	8470	8476	8482	8488	8494	8500	8506	1	1	2	2	3	4	4	5	6
71	8513	8519	8525	8531	8537	8543	8549	8555	8561	8567	1	1	2	2	3	4	4	5	5
72	8573	8579	8585	8591	8597	8603	8609	8615	8621	8627	1	1	2	2	3	4	4	5	5
73	8633	8639	8645	8651	8657	8663	8669	8675	8681	8686	1	1	2	2	3	4	4	5	5
74	8692	8698	8704	8710	8716	8722	8727	8733	8739	8745	1	1	2	2	3	4	4	5	5

75	8751	8756	8762	8768	8774	8779	8785	8791	8797	8802	1	1	2	2	3	3	4	5	5
76	8808	8814	8820	8825	8831	8837	8842	8848	8854	8859	1	1	2	2	3	3	4	5	5
77	8865	8871	8876	8882	8887	8893	8899	8904	8910	8915	1	1	2	2	3	3	4	4	5
78	8921	8927	8932	8938	8943	8949	8954	8960	8965	8971	1	1	2	2	3	3	4	4	5
79	8976	8982	8987	8993	8998	9004	9009	9015	9020	9025	1	1	2	2	3	3	4	4	5
80	9031	9036	9042	9047	9053	9058	9063	9069	9074	9079	2	1	2	2	3	3	4	4	5
81	9085	9090	9096	9101	9106	9112	9117	9122	9128	9133	1	1	2	2	3	3	4	4	5
82	9138	9143	9149	9154	9159	9165	9170	9175	9180	9186	1	1	2	2	3	3	4	4	5
83	9191	9196	9201	9206	9212	9217	9222	9227	9232	9238	1	1	2	2	3	3	4	4	5
84	9243	9248	9253	9258	9263	9269	9274	9279	9284	9289	1	1	2	2	3	3	4	4	5
85	9294	9299	9304	9309	9315	9320	9325	9330	9335	9340	1	1	2	2	3	3	4	4	5
86	9345	9350	9355	9360	9365	9370	9375	9380	9385	9390	1	1	2	2	3	3	4	4	5
87	9395	9400	9405	9410	9415	9420	9425	9430	9435	9440	0	1	1	2	2	3	3	4	4
88	9445	9450	9455	9460	9465	9469	9474	9479	9484	9489	0	1	1	2	2	3	3	4	4
89	9494	9499	9504	9509	9513	9518	9523	9528	9533	9538	0	1	1	2	2	3	3	4	4
90	9542	9547	9552	9557	9562	9566	9571	9576	9581	9586	0	1	1	2	2	3	3	4	4
91	9590	9595	9600	9605	9609	9614	9619	9624	9628	9633	0	1	1	2	2	3	3	4	4
92	9638	9643	9647	9652	9657	9661	9666	9671	9675	9680	0	1	1	2	2	3	3	4	4
93	9685	9689	9694	9699	9703	9708	9713	9717	9722	9727	0	1	1	2	2	3	3	4	4
94	9731	9736	9741	9745	9750	9754	9759	9763	9768	9773	0	1	1	2	2	3	3	4	4
95	9777	9782	9786	9791	9795	9800	9805	9809	9814	9818	0	1	1	2	2	3	3	4	4
96	9823	9827	9832	9836	9841	9845	9850	9854	9859	9863	0	1	1	2	2	3	3	4	4
97	9868	9872	9877	9881	9886	9890	9894	9899	9903	9908	0	1	1	2	2	3	3	4	4
98	9912	9917	9921	9926	9930	9934	9939	9943	9948	9952	0	1	1	2	2	3	3	4	4
99	9956	9961	9965	9969	9974	9978	9983	9987	9991	9996	0	1	1	2	2	3	3	3	4

ANTILOGARITHMS.

	0	1	2	3	4	5	6	7	8	9	1	2	3	4	5	6	7	8	9
·00	1000	1002	1005	1007	1009	1012	1014	1016	1019	1021	0	0	1	1	1	1	2	2	2
·01	1023	1026	1028	1030	1033	1035	1038	1040	1042	1045	0	0	1	1	1	1	2	2	2
·02	1047	1050	1052	1054	1057	1059	1062	1064	1067	1067	0	0	1	1	1	1	2	2	2
·03	1072	1074	1076	1079	1081	1084	1086	1089	1091	1094	0	0	1	1	1	1	2	2	2
·04	1096	1099	1102	1104	1107	1109	1112	1114	1117	1119	0	1	1	1	1	2	2	2	2
·05	1122	1125	1127	1130	1132	1135	1138	1140	1143	1146	0	1	1	1	1	2	2	2	2
·06	1148	1151	1153	1156	1159	1161	1164	1167	1169	1172	0	1	1	1	1	2	2	2	2
·07	1175	1178	1180	1183	1186	1189	1191	1194	1197	1199	0	1	1	1	1	2	2	2	2
·08	1202	1205	1208	1211	1213	1216	1219	1222	1225	1227	0	1	1	1	1	2	2	2	3
·09	1230	1233	1236	1239	1242	1245	1247	1250	1253	1256	0	1	1	1	1	2	2	2	3
·10	1259	1262	1265	1268	1271	1274	1276	1279	1282	1285	0	1	1	1	1	2	2	2	3
·11	1288	1291	1294	1297	1300	1303	1306	1309	1312	1315	0	1	1	1	2	2	2	2	3
·12	1318	1321	1324	1327	1330	1334	1337	1340	1343	1346	0	1	1	1	2	2	2	2	3
·13	1349	1352	1355	1358	1361	1365	1368	1371	1374	1377	0	1	1	1	2	2	2	3	3
14	1380	1384	1387	1390	1393	1396	1400	1403	1406	1409	0	1	1	1	2	2	2	3	3
·15	1413	1416	1419	1422	1426	1429	1432	1435	1439	1442	0	1	1	1	2	2	2	3	3
·16	1445	1449	1452	1455	1459	1462	1466	1469	1472	1476	0	1	1	1	2	2	2	3	3
·17	1479	1483	1486	1489	1493	1496	1500	1503	1507	1510	0	1	1	1	2	2	2	3	3
·18	1514	1517	1521	1524	1528	1531	1535	1538	1542	1545	0	1	1	1	2	2	2	3	3
·19	1549	1552	1556	1560	1563	1567	1570	1574	1578	1581	0	1	1	1	2	2	3	3	3
·20	1585	1589	1592	1596	1600	1603	1607	1611	1614	1618	0	1	1	1	2	2	3	3	3
·21	1622	1626	1629	1633	1637	1641	1644	1648	1652	1656	0	1	1	2	2	2	3	3	3
·22	1660	1663	1667	1671	1675	1679	1683	1687	1690	1694	0	1	1	2	2	2	3	3	3
·23	1698	1702	1706	1710	1714	1718	1722	1726	1730	1734	0	1	1	2	2	2	3	3	4
·24	1738	1742	1746	1750	1754	1758	1762	1766	1770	1774	0	1	1	2	2	2	3	3	4

·25	1778	1782	1786	1791	1795	1799	1803	1807	1811	1816	0	1	1	2	2	2	3	3	4
·26	1820	1824	1828	1832	1837	1841	1845	1849	1854	1858	0	1	1	2	2	3	3	3	4
·27	1862	1866	1871	1875	1879	1884	1888	1892	1897	1901	0	1	1	2	2	3	3	3	4
·28	1905	1910	1914	1919	1923	1928	1932	1936	1941	1945	0	1	1	2	2	3	3	4	4
·29	1950	1954	1959	1963	1968	1972	1977	1982	1986	1991	0	1	1	2	2	3	3	4	4
·30	1995	2000	2004	2009	2014	2018	2023	2028	2032	2037	0	1	1	2	2	3	3	4	4
·31	2042	2046	2051	2056	2061	2065	2070	2075	2080	2084	0	1	1	2	2	3	3	4	4
·32	2089	2094	2099	2104	2109	2113	2118	2123	2128	2133	0	1	1	2	2	3	3	4	4
·33	2138	2143	2148	2153	2158	2163	2168	2173	2178	2183	0	1	1	2	2	3	3	4	4
·34	2188	2193	2198	2203	2208	2213	2218	2223	2228	2234	1	1	2	2	3	3	4	4	5
·35	2239	2244	2249	2254	2259	2265	2270	2275	2280	2286	1	1	2	2	3	3	4	4	5
·36	2291	2296	2301	2307	2312	2317	2323	2328	2333	2339	1	1	2	2	3	3	4	4	5
·37	3344	2350	2355	2360	2366	2371	2377	2382	2388	2393	1	1	2	2	3	3	4	4	5
·38	2399	2404	2410	2415	2421	2427	2432	2438	2443	2459	1	1	2	2	3	3	4	4	5
·39	2455	2460	2466	2472	2477	2483	2489	2495	2500	2506	1	1	2	2	3	3	4	5	5
·40	2512	2518	2523	2529	2535	2541	2547	2553	2559	2564	1	1	2	2	3	4	4	5	5
·41	2570	2576	2582	2588	2594	2600	2606	2612	2618	2624	1	1	2	2	3	4	4	5	5
·42	2630	2636	2642	2649	2655	2661	2667	2673	2679	2685	1	1	2	2	3	4	4	5	6
·43	2692	2698	2704	2710	2716	2723	2729	2735	2742	2748	1	1	2	3	3	4	4	5	6
·44	2754	2761	2767	2773	2780	2786	2793	2799	2805	2812	1	1	2	3	3	4	4	5	6
·45	2818	2825	2831	2838	2844	2851	2858	2864	2871	2877	1	1	2	3	3	4	5	5	6
·46	2884	2891	2897	2904	2911	2917	2924	2931	2938	2944	1	1	2	3	3	4	5	5	6
·47	2951	2958	2965	2972	2979	2985	2992	2999	3006	3013	1	1	2	3	3	4	5	5	6
·48	3020	3027	3034	3041	3048	3055	3062	3069	3076	3083	1	1	2	3	4	4	5	6	6
·49	3090	3097	3105	3112	3119	3126	3133	3141	3148	3155	1	1	2	3	4	4	5	6	6

ANTILOGARITHMS.—*Continued.*

	0	1	2	3	4	5	6	7	8	9	1	2	3	4	5	6	7	8	9
·50	3162	3170	3177	3184	3192	3199	3206	3214	3221	3228	1	1	2	3	4	4	5	6	7
·51	3236	3243	3251	3258	3266	3273	3281	3289	3296	3304	1	2	2	3	4	5	5	6	7
·52	3311	3319	3327	3334	3342	3350	3357	3365	3373	3381	1	2	2	3	4	5	5	6	7
·53	3388	3396	3404	3412	3420	3428	3436	3443	3451	3459	1	2	2	3	4	5	6	6	7
·54	3467	3475	3483	3491	3499	3508	3516	3524	3532	3540	1	2	2	3	4	5	6	6	7
·55	3548	3556	3565	3573	3581	3580	3597	3606	3614	3622	1	2	2	3	4	5	6	7	7
·56	3631	3639	3648	3656	3664	3673	3681	3690	3698	3707	1	2	3	3	4	5	6	7	8
·57	3715	3724	3733	3741	3750	3758	3767	3776	3784	3793	1	2	3	3	4	5	6	7	8
·58	3802	3811	3819	3828	3837	3846	3855	3864	3873	3882	1	2	3	4	4	5	6	7	8
·59	3890	3899	3908	3917	3926	3936	3945	3954	3963	3972	1	2	3	4	5	5	6	7	8
·60	3981	3990	3999	4009	4018	4027	4036	4046	4055	4064	1	2	3	4	5	6	6	7	8
·61	4074	4083	4093	4102	4111	4121	4130	4140	4150	4159	1	2	3	4	5	6	7	8	9
·62	4169	4178	4188	4198	4207	4217	4227	4236	4246	4256	1	2	3	4	5	6	7	8	9
·63	4266	4276	4285	4295	4305	4315	4325	4335	4345	4355	1	2	3	4	5	6	7	8	9
·64	4365	4375	4385	4395	4406	4416	4426	4436	4446	4457	1	2	3	4	5	6	7	8	9
·65	4467	4477	4487	4498	4508	4519	4529	4539	4550	4560	1	2	3	4	5	6	7	8	9
·66	4571	4581	4692	4603	4613	4624	4634	4645	4656	4667	1	2	3	4	5	6	7	9	10
·67	4677	4688	4699	4710	4721	4732	4742	4753	4764	4775	1	2	3	4	5	7	8	9	10
·68	4786	4797	4808	4819	4831	4842	4853	4864	4875	4887	1	2	3	4	6	7	8	9	10
·69	4898	4909	4920	4932	4943	4955	4966	4977	4989	5000	1	2	3	5	6	7	8	9	10
·70	5012	5023	5035	5047	5058	5070	5082	5093	5105	5117	1	2	4	5	6	7	8	9	11
·71	5129	5140	5152	5164	5176	5188	5200	5212	5224	5236	1	2	4	5	6	7	8	10	11
·72	5248	5260	5272	5284	5297	5309	5321	5333	5346	5358	1	2	4	5	6	7	9	10	11
·73	5370	5383	5395	5408	5420	5433	5445	5458	5470	5483	1	3	4	5	6	8	9	10	11
·74	5495	5508	5521	5534	5546	5559	5572	5585	5598	5610	1	3	4	5	6	8	9	10	12

·75	5623	5636	5649	5662	5675	5689	5702	5715	5728	5741	1	3	4	5	7	8	9	10	12
·76	5754	5768	5781	5794	5808	5821	5834	5848	5861	5875	1	3	4	5	7	8	9	11	12
·77	5888	5902	5916	5929	5943	5957	5970	5984	5998	6012	1	3	4	5	7	8	10	11	12
·78	6026	6039	6053	6067	6081	6095	6109	6124	6138	6152	1	3	4	6	7	8	10	11	12
·79	6166	6180	6194	6209	6223	6237	6252	6266	6281	6295	1	3	4	6	7	9	10	11	13
·80	6310	6324	6339	6353	6368	6383	6397	6412	6427	6442	1	3	4	6	7	9	10	12	13
·81	6457	6471	6486	6501	6516	6531	6546	6561	6577	6592	2	3	5	6	8	9	11	12	14
·82	6607	6622	6637	6653	6668	6683	6699	6714	6730	6745	2	3	5	6	8	9	11	12	14
·83	6761	6776	6792	6808	6823	6839	6855	6871	6887	6902	2	3	5	6	8	9	11	13	14
·84	6918	6934	6950	6966	6982	6998	7515	7031	7047	7063	2	3	5	6	8	10	11	13	15
·85	7079	7096	7112	7129	7145	7161	7178	7194	7211	7228	2	3	5	7	8	10	12	13	15
·86	7244	7261	7278	7295	7311	7328	7345	7362	7379	7396	2	3	5	7	8	10	12	13	15
·87	7413	7430	7447	7464	7482	7499	2516	7534	7551	7568	2	3	5	7	9	10	12	14	16
·88	7586	7603	7621	7638	7656	7674	7691	7709	7727	7745	2	4	5	7	9	11	12	14	16
·89	7762	7780	7798	7816	7834	7852	7870	7889	7907	7925	2	4	5	7	9	11	13	14	16
·90	7943	7962	7980	7998	8017	8035	8054	8072	8091	8110	2	4	6	7	9	11	13	15	17
·91	8128	8147	8166	8185	8204	8222	8241	8260	8279	8299	2	4	6	8	9	11	13	15	17
·92	8318	8337	8356	8375	8395	8414	8433	8453	8472	8492	2	4	6	8	10	12	14	15	17
·93	8511	8531	8551	8570	8590	8610	8630	8650	8670	8690	2	4	6	8	10	12	14	16	18
·94	8710	8730	8750	8770	8790	8810	8831	8851	8872	8892	2	4	6	8	10	12	14	16	18
·95	8913	8933	8954	8974	8995	9016	9036	9057	9078	9099	2	4	6	8	10	12	15	17	19
·96	9120	9141	9162	9183	9204	9226	9247	9268	9290	9311	2	4	6	8	11	13	15	17	19
·97	9333	9354	9376	9397	9419	9441	9462	9484	9506	9528	2	4	7	9	11	13	15	17	20
·98	9550	9572	9594	9616	9638	9661	9683	9705	9727	9750	2	4	7	9	11	13	16	18	20
·99	9772	9795	9817	9840	9863	9886	9908	9931	9954	9977	2	5	7	9	11	14	16	18	20

TRIGONOMETRICAL FUNCTIONS.

Angle.		Chord.	Sine.	Tangent.	Co-tangent	Cosine.			
Degrees.	Radians.								
0°	0	0	0	0	∞	1	1·414	1·5708	90°
1	·0175	·017	·0175	·0175	57·2900	·9998	1·402	1·5533	89
2	·0349	·035	·0349	·0349	28·6363	·9994	1·389	1·5359	88
3	·0524	·052	·0523	·0524	19·0811	·9986	1·377	1·5184	87
4	·0698	·070	·0698	·0699	14·3007	·9976	1·364	1·5010	86
5	·0873	·087	0·872	·0875	11·4301	·9962	1·351	1·4835	85
6	·1047	·105	·1045	·1051	9·5144	·9945	1·338	1·4661	84
7	·1222	·122	·1219	·1228	8·1443	·9925	1·325	1·4486	83
8	·1396	·140	·1392	·1405	7·1154	·9903	1·312	1·4312	82
9	·1571	·157	·1564	·1584	6·3138	·9877	1·299	1·4137	81
10	·1745	·174	·1736	·1763	5·6713	·9848	1·286	1·3963	80
11	·1920	·192	·1908	·1944	5·1446	·9816	1·272	1·3788	79
12	·2094	·209	·2079	·2126	4·7046	·9781	1·259	1·3614	78
13	·2269	·226	·2250	·2309	4·3315	·9744	1·245	1·3439	77
14	·2443	·244	·2419	·2493	4·0108	·9703	1·231	1·3265	76
15	·2618	·261	·2588	·2679	3·7321	·9659	1·218	1·3090	75
16	·2793	·278	·2756	·2867	3·4874	·9613	1·204	1·2915	74
17	·2967	·296	·2924	·3057	3·2709	·9563	1·190	1·2741	73
18	·3142	·313	·3090	·3249	3·0777	·9511	1·176	1·2566	72
19	·3316	·330	·3256	·3443	2·9042	·9455	1·161	1·2392	71
20	·3491	·347	·3420	·3640	2·7475	·9397	1·147	1·2217	70°
21	·3665	·364	·3584	·3839	2·6051	·9336	1·133	1·2043	69
22	·3840	·382	·3746	·4040	2·4751	·9272	1·118	1·1868	68
23	·4014	·399	·3907	·4245	2·3559	·9205	1·104	1·1694	67

25	·4363	·433	·4226	·4663	2·1445	·9063	1·075	1·1345	65
26	·4538	·450	·4384	·4877	2·0503	·8988	1·060	1·1170	64
27	·4712	·467	·4540	·5095	1·9626	·8910	1·045	1·0996	63
28	·4887	·484	·4695	·5317	1·8807	·8829	1·030	1·0821	62
29	·5061	·501	·4848	·5543	1·8040	·8746	1·015	1·0647	61
30	·5236	·518	·5000	·5774	1·7321	·8660	1·000	1·0472	60
31	·5411	·534	·5150	·6009	1·6643	·8572	·985	1·0297	59
32	·5585	·551	·5299	·6249	1·6003	·8480	·970	1·0123	58
33	·5760	·568	·5446	·6494	1·5399	·8387	·954	·9948	57
34	·5934	·585	·5592	·6745	1·4826	·8290	·939	·9774	56
35	·6109	·601	·5736	·7002	1·4281	·8192	·923	·9599	55
36	·6283	·618	·5878	·7265	1·3764	·8090	·908	·9425	54
37	·6458	·635	·6018	·7536	1·3270	·7986	·892	·9250	53
38	·6632	·651	·6157	·7813	1·2799	·7880	·877	·9076	52
39	·6807	·668	·6293	·8098	1·2349	·7771	·861	·8901	51
40	·6981	·684	·6428	·8391	1·1918	·7660	·845	·8727	50
41	·7156	·700	·6561	·8693	1·1504	·7547	·829	·8552	49
42	·7330	·717	·6691	·9004	1·1106	·7431	·813	·8378	48
43	·7505	·733	·6820	·9325	1·0724	·7314	·797	·8203	47
44	·7679	·749	·6947	·9657	1·0355	·7193	·781	·8029	46
45°	·7854	·765	·7071	1·0000	1·0000	·7071	·765	·7854	45°
			Cosine.	Co-tangent.	Tangent.	Sine.	Chord	Radians.	Degrees.
								Angle	

TABLE OF SQUARES, CUBES ETC.

No.	Square.	Cube	Square Root.	Cube Root	No	Square	Cube.	Square Root.	Cube Root.
1	1	1		1	6	36	216	2·4495	1·8171
1·1	1·21	1·331	1·0488	1·0323	6·1	37·21	226·981	2·4698	1·8272
1·2	1·44	1·728	1·0955	1·0627	6·2	38·44	238·328	2·49	1·8371
1·3	1·69	2·197	1·1402	1·0914	6·3	39·69	250·047	2·51	1·8469
1·4	1·96	2·744	1·1882	1·1187	6·4	40·96	262·144	2·5298	1·8566
1·5	2·25	3·375	1·2247	1·1447	6·5	42·25	274·625	2·5495	1·8663
1·6	2·56	4·096	1·2649	1·1696	6·6	43·56	287·496	2·569	1·8758
1·7	2·89	4·913	1·3038	1·1935	6·7	44·89	300·763	2·5884	1·8852
1·8	3·24	5·832	1·3416	1·2164	6·8	46·24	314·432	2·6077	1·8945
1·9	3·61	6·859	1·3784	1·2386	6·9	47·61	328·509	2·6268	1·9038
2	4	8	1·4142	1·2599	7	49	343	2·6458	1·9129
2·1	4·41	9·261	1·4491	1·2806	7·1	50·41	357·911	2·6646	1·922
2·2	4·84	10·648	1·4832	1·3006	7·2	51·84	373·248	2·6833	1·931
2·3	5·29	12·167	1·5166	1·32	7·3	53·29	389·017	2·7019	1·9399
2·4	5·76	13·824	1·5492	1·3389	7·4	54·76	405·224	2·7203	1·9487
2·5	6·25	15·625	1·5811	1·3572	7·5	56·25	421·875	2·7386	1·9574
2·6	6·76	17·576	1·6125	1·3751	7·6	57·76	438·976	2·7568	1·9661
2·7	7·29	19·683	1·6432	1·3925	7·7	59·29	456·533	2·7749	1·9747
2·8	7·84	21·952	1·6733	1·4095	7·8	60·84	474·552	2·7928	1·9832
2·9	8·41	24·389	1·7029	1·426	7·9	62·41	493·039	2·8107	1·9916
3	9	27	1·7321	1·4422	8	64	512	2·8284	2
3·1	9·61	29·791	1·7607	1·4581	8·1	65·61	531·441	2·846	2·0083
3·2	10·24	32·768	1·7889	1·4736	8·2	67·24	551·368	2·8636	2·0165
3·3	10·89	35·937	1·8166	1·4888	8·3	68·89	571·787	2·881	2·0247
3·4	11·56	39·304	1·8439	1·5037	8·4	70·56	592·704	2·8983	2·0328
3·5	12·25	42·875	1·8708	1·5183	8·5	73·25	614·125	2·9155	2·0408
3·6	12·96	46·656	1·8974	1·5326	8·6	73·96	636·056	2·9325	2·0488
3·7	13·69	50·653	1·9235	1·5467	8·7	75·69	658·503	2·9496	2·0567
3·8	14·44	54·872	1·9494	1·5605	8·8	77·44	681·472	2·9665	2·0646
3·9	15·21	59·319	1·9748	1·5741	8·9	79·21	704·969	2·9833	2·0724
4	16	64	2	1·5874	9	81	729	3	2·0801
4·1	16·81	68·921	2·0249	1·6005	9·1	82·81	753·571	3·0166	2·0878
4·2	17·64	74·088	2·0494	1·6134	9·2	84·64	778·688	3·0332	2·0954
4·3	18·49	79·507	2·0736	1·6261	9·3	86·49	804·357	3·0496	2·1029
4·4	19·36	85·184	2·0976	1·6386	9·4	88·36	830·584	3·0659	2·1105
4·5	20·25	91·125	2·1213	1·651	9·5	90·25	857·375	3·0822	2·1179
4·6	21·16	97·336	2·1448	1·6631	9·6	92·16	884·736	3·0984	2·1253
4·7	22·09	103·823	2·1680	1·6751	9·7	94·09	912·673	3·1145	2·1327
4·8	23·04	110·592	2·1909	1·6869	9·8	96·04	941·192	3·1305	2·14
4·9	24·01	117·649	2·2136	1·6985	9·9	98·01	970·299	3·1464	2·1472
5	25	125	2·2361	1·71	10	100	1000	3·1623	2·1544
5·1	26·01	132·651	2·2583	1·7213	10·1	102·01	1030·301	3·178	2·1616
5·2	27·04	140·608	2·2804	1·7325	10·2	104·04	1061·208	3·1937	2·1687
5·3	28·09	148·877	2·3022	1·7435	10·3	106·09	1092·727	3·2094	2·1757
5·4	29·16	157·464	2·3238	1·7544	10·4	108·16	1124·863	3·2249	2·1828
5·5	30·25	166·375	2·3452	1·7652	10·5	110·25	1157·625	3·2404	2·1897
5·6	31·36	175·616	2·3664	1·7758	10·6	112·36	1191·016	3·2558	2·1967
5·7	32·49	185·193	2·3875	1·7863	10·7	114·49	1225·043	3·2711	2·2036
5·8	33·64	195·112	2·4083	1·7967	10·8	116·64	1259·712	3·2863	2·2104
5·9	34·81	205·379	2·429	1·807	10·9	118·81	1295·029	3·3015	2·2172

TABLE OF SQUARES, ETC.—*Continued.*

No.	Square.	Cube	Square Root	Cube Root	No.	Square.	Cube.	Square Root	Cube Root.
11	121	1331	3·3166	2·2239	16	256	4096	4	2·5198
11·1	123·21	1367·631	3·3317	2·2307	16·1	259·21	4173·281	4·0125	2·5251
11·2	125·44	1406 928	3·3466	2·2374	16·2	262·44	4251·528	4 0249	2·5303
11·3	127·69	1442·897	3·3615	2·2441	16·3	265·69	4330·747	4·0373	2·5355
11·4	129·96	1481·544	3·3764	2·2506	16·4	268·96	4410 944	4 0497	2·5407
11·5	132·25	1520·875	3·3912	2·2572	16·5	272·25	4492·125	4·062	2·5458
11·6	134·56	1560 896	3·4059	2·2637	16·6	275·56	4574·296	4·0743	2·5509
11·7	136·89	1601·613	3·4205	2·2702	16·7	278·89	4657·463	4·0866	2·5561
11·8	139·24	1643·032	3·4351	2·2766	16·8	282·24	4741·632	4 0988	2·5612
11·9	141·61	1685·159	3·4496	2·2831	16·9	285·61	4826·809	4·111	2·5662
12	144	1728	3·4641	2·2894	17	289	4913	4·1231	2·5713
12·1	146·41	1771·561	3·4785	2·2957	17·1	292·41	5000·211	4 1352	2·5763
12·2	148·84	1815·848	3·4928	2·3021	17·2	295·84	5088·448	4·1473	2·5813
12·3	151·29	1860·867	3·5071	2·3084	17·3	299·29	5177·717	4·1593	2·5863
12·4	153·76	1906·624	3·5214	2·3146	17·4	302·76	5268·024	4·1713	2·5913
12·5	156·25	1953·125	3·5355	2·3298	17·5	306 25	5359·375	4·1833	2·5962
12·5	158·76	2000·376	3·5496	2·327	17·6	309·76	5451·776	4·1952	2·6012
12·7	161·29	2048·383	3·5637	2·3331	17·7	313·29	5545·233	4·2071	2·6061
12·8	163·84	2097·152	3·5777	2·3391	17·8	316·84	5639·752	4·219	2·611
12·9	166·41	2146·689	3·5917	2·3453	17·9	320·41	5735·339	4·2308	2·6159
13	169	2197	3·6056	2·3513	18	324	5832	4·2426	2·6207
13·1	171·61	2248·091	3·6194	2·3573	18·1	327·61	5929·741	4·2544	2·6256
13·2	174·24	2299·968	3·6332	2·3633	18·2	331·24	6028·568	4·2661	2·6304
13·3	176·89	2352·637	3·6469	2·3693	18·3	334·89	6128·487	4·2778	2·6352
13·4	179·56	2406·104	3·6606	2·3752	18·4	338·56	6229·504	4·2895	2·64
13·5	182·25	2460·375	3·6742	2·3811	18·5	342·25	6331·625	4·3012	2·6448
13·6	184·96	2515·456	3·6878	2·387	18·6	345·96	6434·856	4·3128	2·6495
13·7	187·69	2571·353	3·7013	2·3928	18·7	349·69	6539·203	4·3248	2·6543
13·8	190·44	2628·072	3·7148	2·3986	18·8	353·44	6644·672	4·3359	2·659
13·9	193·21	2685·619	3·7283	2·4044	18·9	357·21	6751·269	4·3474	2·6637
14	196	2744	3·7417	2·4101	19	361	6859	4·3589	2·6684
14·1	198·81	2803·221	3·755	2·4159	19·1	364·81	6967·871	4·3704	2·6731
14·2	201·64	2863·288	3·7683	2·4216	19·2	368·64	7077·888	4·3818	2·6777
14·3	204·49	2924·207	3·7815	2·4272	19·3	372·49	7189·057	4·3932	2·6824
14·4	207·36	2985·984	3·7947	2·4329	19·4	376·36	7301·384	4·4045	2·6870
14·5	210·25	3048·625	3·8079	2·4385	19·5	380·25	7414·875	4·4159	2·6916
14·6	213·16	3112·136	3·821	2·4441	19·6	384·16	7529·536	4·4272	2·6962
14·7	216·09	3176·523	3·8341	2·4497	19·7	388·09	7645·373	4·4385	2·7008
14·8	219·04	3241·792	3·8471	2·4552	19·8	392·04	7762·392	4·4497	2·7053
14·9	222·01	3307·949	3·86	2·4607	19·9	396·01	7880·599	4·4609	2·7099
15	225	3375	3·873	2·4662	20	400	8000	4·4721	2·7144
15·1	228·01	3442·951	3·8859	2·4717	20·1	404·01	8120·601	4·4833	2·7189
15·2	231·04	3511·808	3·8987	2·4771	20·2	408·04	8242·408	4·4944	2·7234
15·3	234·09	3581·577	3·9115	2·4825	20·3	412·09	8365·427	4·5055	2·7279
15·4	237·16	3652·264	3·9243	2·4879	20·4	416·16	8489·664	4·5166	2·7324
15·5	240·25	3723·875	3·937	2·4933	20·5	420·25	8615·125	4·5277	2·7368
15·6	243·36	3796·416	3·9497	2·4987	20·6	424·36	8741·816	4·5387	2·7413
15·7	246·49	3869·893	3·9623	2·504	20·7	428·49	8869·743	4·5497	2·7457
15·8	249·64	3944·312	3·9749	2·5093	20·8	432·64	8998·912	4·5607	2·7502
15·9	252·81	4019·679	3·9875	2·5146	20·9	436·81	9129·329	4·5716	2·7545

TABLE OF SQUARES, ETC.—*Continued.*

No.	Square	Cube.	Square Root.	Cube Root.	No.	Square.	Cube.	Square Root.	Cube Root.
21	441	9261	4·5826	2·7589	26	676	17576	5·099	2·9625
21·1	445·21	9393·931	4·5935	2·7633	26·1	681·21	17779·581	5·1088	2·9663
21·2	449·44	9528·128	4·6043	2·7676	26·2	686·44	17984·728	5·1186	2·9701
21·3	453·69	9663·597	4·6152	2·772	26·3	691·69	18191·447	5·1284	2·9738
21·4	457·96	9800·344	4·626	2·7763	26·4	696·96	18399·744	5·1381	2·9776
21·5	462·25	9938·375	4·6368	2·7806	26·5	702·25	18609·625	5·1478	2·9814
21·6	466·56	10077·696	4·6476	2·7849	26·6	707·56	18821·096	5·1575	2·9851
21·7	470·89	10218·313	4·6586	2·7893	26·7	712·89	19034·163	5·1672	2·9888
21·8	475·24	10360·232	4·669	2·7935	26·8	718·24	19248·832	5·1769	2·9926
21·9	479·61	10503·459	4·6797	2·7978	26·9	723·61	19465·109	5·1865	2·9963
22	484	10648	4·6904	2·8021	27	729	19683	5·1962	3
22·1	488·41	10793·861	4·7011	2·8063	27·1	734·41	19902·511	5·2058	3·0037
22·2	492·84	10941·048	4·7117	2·8105	27·2	739·84	20123·648	5·2154	3·0074
22·3	497·29	11089·567	4·7223	2·8147	27·3	745·29	20346·417	5·2249	3·0111
22·4	501·76	11239·424	4·7329	2·8189	27·4	750·76	20570·824	5·2345	3·0147
22·5	506·25	11390·625	4·7434	2·8231	27·5	756·25	20796·875	5·244	3·0184
22·6	510·76	11543·176	4·7539	2·8273	27·6	761·76	21024·576	5·2536	3·0221
22·7	515·29	11697·083	4·7644	2·8314	27·7	767·29	21353·933	5·2631	3·0257
22·8	519·84	11852·352	4·7749	2·8356	27·8	772·84	21484·952	5·2726	3·0293
22·9	524·41	12008·989	4·7854	2·8397	27·9	778·41	21717·639	5·282	3·033
23	529	12167	4·7958	2·8438	28	784	21952	5·2915	3·0366
23·1	533·61	12326·391	4·8062	2·8479	28·1	789·61	22188·041	5·3509	3·0402
23·2	538·24	12487·168	4·8166	2·8521	28·2	795·24	22425·768	5·3104	3·0438
23·3	542·89	12649·337	4·827	2·8562	28·3	800·89	22665·187	5·3198	3·0474
23·4	547·56	12812·904	4·8373	2·8603	28·4	806·56	22906·304	5·3292	3·051
23·5	552·25	12977·875	4·8477	2·8643	28·5	812·26	23149·125	5·3385	3·0546
23·6	556·96	13141·256	4·858	2·8684	28·6	817·96	23393·656	5·3479	3·0581
23·7	561·69	13312·053	4·8683	2·8724	28·7	823·69	23639·903	5·3572	3·0617
23·8	566·44	13481·272	4·8785	2·8765	28·8	829·44	23887·872	5·3666	3·0652
23·9	571·21	13651·919	4·8888	2·8805	28·9	835·21	24137·569	5·3759	3·0688
24	576	13824	4·899	2·8845	29	841	24389	5·3852	3·0723
24·1	580·81	13997·521	4·9092	2·8885	29·1	846·81	24642·171	5·3944	3·0758
24·2	585·64	14172·488	4·9193	2·8925	29·2	852·64	24897·088	5·4037	3·0794
24·3	590·49	14348·907	4·9295	2·8965	29·3	858·49	25153·757	5·4129	3·0829
24·4	595·36	14526·784	4·9396	2·9004	29·3	864·36	25412·184	5·4222	3·0864
24·5	600·25	14706·125	4·9497	2·9044	29·5	870·25	25672·375	5·4314	3·0899
24·6	605·16	14886·936	4·9598	2·9083	29·6	876·16	25934·336	5·4406	3·0934
24·7	610·09	15069·223	4·9699	2·9123	29·7	882·09	26198·073	5·4498	3·0968
24·8	615·04	15252·992	4·9799	2·9162	29·8	888·04	26463·592	5·4589	3·1003
24·9	620·01	15438·249	4·9899	2·9201	29·9	894·01	26730·899	5·4681	3·1038
25	625	15625	5	2·9240	30	900	27000	5·4772	3·1072
25·1	630·01	15813·251	5·01	2·9279	30·1	906·01	27270·901	5·4863	3·1107
25·2	635·04	16003·008	5·02	2·9318	30·2	912·04	27543·608	5·4954	3·1141
25·3	640·09	16194·277	5·0299	2·9357	30·3	918·09	27818·127	5·5045	3·1176
25·4	645·16	16387·064	5·0398	2·9395	30·4	924·16	28094·464	5·5136	3·121
25·5	650·25	16581·375	5·0498	2·9434	30·5	930·25	28372·625	5·5226	3·1244
25·6	655·36	16777·216	5·0596	2·9472	30·6	936·36	28652·616	5·5317	3·1278
25·7	660·49	16974·593	5·0695	2·9511	30·7	942·49	28934·443	5·5407	3·1312
25·8	665·64	17173·512	5·0794	2·9549	30·8	948·64	29218·112	5·5497	3·1346
25·9	670·81	17373·979	5·0892	2·9587	30·9	954·81	29503·629	5·5587	3·188

TABLE OF SQUARES, ETC.—*Continued.*

No.	Square.	Cube.	Square Root.	Cube Root	No.	Square.	Cube	Square Root.	Cube Root.
31	961	29791	5·5678	3·1414	36	1296	46656	6	3·3019
31·1	967·21	30080·231	5·5767	3·1448	36·1	1303·21	47045·881	6·0083	3·305
31·2	973·44	30371·328	5·5857	3·1481	36·2	1310·44	47437·928	6·0166	3·308
31·3	979·69	30664·297	5·5946	3·1515	36·3	1317·69	47832·147	6·0249	3·3111
31·4	985·96	30959·144	5·6035	3·1548	36·4	1324·96	48228·544	6·0332	3·3141
31·5	992·25	31255·875	5·6124	3·1582	36·5	1332·25	48627·125	6·0415	3·3171
31·6	998·56	31554·496	5·6213	3·1615	36·6	1339·56	49027·896	6·0498	3·3202
31·7	1004·89	31855·013	5·6302	3·1648	36·7	1346·89	49430·863	6·0581	3·3232
31·8	1011·24	32157·432	5·6391	3·1671	36·8	1354·24	49836·032	6·0663	3·3262
31·9	1017·61	32461·759	5·648	3·1715	36·9	1361·61	50243·409	6·0745	3·3292
32	1024	32768	5·6569	3·1748	37	1369	50653	6·0828	3·3322
32·1	1030·41	33076·161	5·6656	3·1781	37·1	1376·41	51064·811	6·091	3·3352
32·2	1036·84	33386·248	5·6745	3·1814	37·2	1383·84	51478·848	6·0992	3·3382
32·3	1043·29	33698·267	5·6833	3·1847	37·3	1391·29	51895·117	6·1074	3·3412
32·4	1049·76	34012·224	5·6921	3·188	37·4	1398·76	52313·624	6·1156	3·3442
32·5	1056·25	34328·125	5·7008	3·1913	37·5	1406·25	52734·375	6·1237	3·3472
32·6	1062·76	34645·976	5·7096	3·1945	37·6	1413·76	53157·376	6·1319	3·3501
32·7	1069·29	34965·783	5·7183	3·1978	37·7	1421·29	53582·633	6·14	3·3531
32·8	1075·84	35287·552	5·7271	3·201	37·8	1428·84	54010·152	6·1482	3·3561
32·9	1082·41	35611·289	5·7358	3·2043	37·9	1436·41	54439·939	6·1563	3·359
33	1089	35937	5·7446	3·2075	38	1444	54872	6·1644	3·362
33·1	1095·61	36264·691	5·7532	3·2108	38·1	1451·61	55306·341	6·1725	3·3649
33·2	1102·24	36594·368	5·7619	3·214	38·2	1459·24	55742·968	6·1806	3·3679
33·3	1108·89	36926·037	5·7706	3·2172	38·3	1466·89	56181·887	6·1887	3·3708
33·4	1115·56	37259·704	5·7792	3·2204	38·4	1474·56	56623·104	6·1967	3·3737
33·5	1132·25	37595·375	5·7879	3·2237	38·5	1482·25	57066·625	6·2048	3·3767
33·6	1128·96	37933·056	5·7965	3·2269	38·6	1489·96	57512·456	6·2129	3·3796
33·7	1135·69	38272·753	5·8051	3·2301	38·7	1497·69	57960·603	6·2209	3·3825
33·8	1142·44	38614·472	5·8137	3·2332	38·8	1505·44	58411·072	6·229	3·3854
33·9	1149·21	38958·219	5·8223	3·2364	38·9	1513·21	58863·869	6·237	3·3883
34	1156	39304	5·831	3·2396	39	1521	59319	6·245	3·3912
34·1	1162·81	39651·821	5·8395	3·2428	39·1	1528·81	59776·471	6·253	3·3941
34·2	1169·64	40001·688	5·848	3·246	39·2	1536·64	60236·288	6·261	3·397
34·3	1176·49	40353·607	5·8566	3·2491	39·3	1544·49	60698·457	6·269	3·3999
34·4	1183·36	40707·584	5·8651	3·2522	39·4	1552·36	61162·984	6·2769	3·4028
34·5	1190·25	41063·625	5·8736	3·2554	39·5	1560·25	61629·875	6·2849	3·4056
34·6	1197·16	41421·736	5·8821	3·2586	39·6	1568·16	62099·136	6·2929	3·4085
34·7	1204·09	41781·923	5·8906	3·2617	39·7	1576·09	62570·773	6·3008	3·4114
34·8	1211·04	42144·192	5·8991	3·2648	39·8	1584·04	63044·792	6·3087	3·4142
34·9	1218·01	42508·549	5·9076	3·2679	39·9	1592·01	63521·199	6·3166	3·4171
35	1225	42875	5·9161	3·2711	40	1600	64000	6·3246	3·42
35·1	1232·01	43243·551	5·9245	3·2742	40·1	1608·01	64481·201	6·3325	3·4228
35·2	1239·04	43614·208	5·933	3·2773	40·2	1616·04	64964·808	6·3404	3·4256
35·3	1246·09	43986·977	5·9414	3·2804	40·3	1624·09	65450·827	6·3482	3·4285
35·4	1253·16	44361·864	5·9498	3·2835	40·4	1632·16	65939·264	6·3561	3·4313
35·5	1260·25	44738·875	5·9582	3·2866	40·5	1640·25	66430·125	6·3639	3·4341
35·6	1267·36	45118·016	5·9666	3·2897	40·6	1648·36	66923·416	6·3718	3·437
35·7	1274·49	45499·293	5·9749	3·2927	40·7	1656·49	67419·143	6·3796	3·4398
35·8	1281·64	45882·712	5·9833	3·2958	40·8	1664·64	67911·312	6·3875	3·4426
35·9	1288·81	46268·279	5·9917	3·2989	40·9	1672·81	68417·929	6·3953	3·4454

TABLE OF SQUARES, ETC.—*Continued*

No.	Square.	Cube.	Square Root.	Cube Root.	No.	Square	Cube.	Square Root.	Cube. Root.
41	1681	68921	6·4031	3·4482	46	2116	97336	6·7823	3·583
41·1	1689·21	69426·531	6·4109	3·451	46·1	2125·21	97972·181	6·7897	3·5856
41·2	1697·44	69934·528	6·4187	3·4538	46·2	2134·44	98611·128	6·7971	3·5882
41·3	1705·69	70444·997	6·4265	3·4566	46·3	2143·69	99252·847	6·8044	3·5908
41·4	1713·96	70957·944	6·4343	3·4594	46·4	2152·96	99897·344	6·8118	3·5934
41·5	1722·25	71473·375	6·4421	3·4622	46·5	2162·25	100544·625	6·8191	3·596
41·6	1730·56	71991·296	6·4498	3·465	46·6	2171·56	101194·696	6·8264	3·5986
41·7	1738·89	72511·713	6·4575	3·4677	46·7	2180·89	101847·563	6·8337	3·6011
41·8	1747·24	73034·632	6·4653	3·4705	46·8	2190·24	102503·232	6·8411	3·6037
41·9	1755·61	73560·059	6·473	3·4733	46·9	2199·61	103161·709	6·8484	3·6063
42	1764	74088	6·4807	3·476	47	2209	103823	6·8557	3·6088
42·1	1772·41	74618·461	6·4884	3·4788	47·1	2218·41	104487·111	6·8629	3·6114
42·2	1780·84	75151·448	6·4961	3·4815	47·2	2227·84	105154·048	6·8702	3·6139
42·3	1789·29	75686·967	6·5038	3·4843	47·3	2237·29	105823·817	6·8775	3·6165
42·4	1797·76	76225·024	6·5115	3·487	47·4	2246·76	106496·424	6·8848	3·619
42·5	1806·2	76765·625	6·5192	3·4898	47·5	2256·25	107171·875	6·892	3·6216
42·6	1814·76	77308·776	6·5268	3·4915	47·6	2265·76	107850·176	6·8993	3·6241
42·7	1823·29	77854·483	6·5345	3·4952	47·7	2275·29	108531·333	6·9065	3·6267
42·8	1831·84	78402·752	6·5422	3·498	47·8	2284·84	109215·352	6·9138	3·6292
42·9	1840·41	78953·589	6·5498	3·5007	47·9	2294·41	109902·239	6·921	3·6317
43	1849	79507	6·5574	3·5034	48	2304	110592	6·9282	3·6342
43·1	1857·61	80062·991	6·5651	3·5061	48·1	2313·61	111284·641	6·9354	3·6368
43·2	1866·24	80621·568	6·5727	3·5088	48·2	2323·24	111980·168	6·9426	3·6393
43·3	1874·89	81182·737	6·5803	3·5115	48·3	2332·89	112678·587	6·9498	3·6418
43·4	1883·56	81746·504	6·5879	3·5142	48·4	2342·56	113379·904	6·957	3·6443
43·5	1892·25	82312·875	6·5954	3·5169	48·5	2352·25	114084·125	6·9642	3·6468
43·6	1900·96	82881·856	6·603	3·5196	48·6	2361·96	114791·256	6·9714	3·6493
43·7	1909·69	83453·453	6·6106	3·5223	48·7	2371·69	115501·303	6·9785	3·6518
43·8	1918·44	84027·672	6·6182	3·525	46·8	2381·44	116214·272	6·9857	3·6543
43·9	1927·21	84604·519	6·6257	3·5277	48·9	2391·21	116930·169	6·9929	3·6568
44	1936	85184	6·6332	3·5303	49	2401	117649	7	3·6593
44·1	1944·81	85766·121	6·6408	3·533	49·1	2410·81	118370·771	7·0071	3·6618
44·2	1953·64	86350·888	6·6483	3·5357	49·2	2420·64	119095·488	7·0143	3·6643
44·3	1962·49	86938·307	6·6558	3·5384	49·3	2430·49	119823·157	7·0214	3·6668
44·4	1971·36	87528·384	6·6633	3·541	49·4	2440·36	120553·784	7·0285	3·6692
44·5	1980·25	88121·125	6·6708	3·5437	49·5	2450·25	121287·375	7·0356	3·6717
44·6	1989·16	88716·536	6·6783	3·5463	49·6	2460·16	122023·936	7·0427	3·6742
44·7	1998·09	89314·623	6·6858	3·549	49·7	2470·09	122763·473	7·0498	3·6766
44·8	2007·04	89915·392	6·6933	3·5516	49·8	2480·04	123505·992	7·0569	3·6791
44·9	2016·01	90518·849	6·7007	3·5543	49·9	2490·01	124251·499	7·064	3·6816
45	2025	91125	6·7082	3·5569	50	2500	125000	7·0711	3·684
45·1	2034·01	91733·851	6·7157	3·5595	51	2601	132651	7·1414	3·7084
45·2	2043·04	92345·408	6·7231	3·5622	52	2704	140608	7·2111	3·782
45·3	2052·90	92959·677	6·7305	3·5648	53	2809	148877	7·2801	3·756
45·4	2061·16	93576·664	6·738	3·5674	54	2916	157464	7·3485	3·779
45·5	2070·25	94196·375	6·7454	3·57	55	3025	166375	7·4162	3·803
45·6	2079·36	94818·816	6·7528	3·5726	56	3136	175616	7·4833	3·825
45·7	2088·49	95443·993	6·7602	3·5752	57	3249	185193	7·5498	3·848
45·8	2097·64	96071·912	6·7676	3·5778	58	3364	195112	7·6158	3·870
45·9	2106·81	96702·579	6·775	3·5805	59	3481	205379	7·6811	3·893

TABLE OF SQUARES, ETC.—*Continued.*

No.	Square.	Cube.	Square Root.	Cube Root.	No.	Square	Cube.	Square Root.	Cube Root.
60	3600	216000	7·746	3·9149	80	6400	512000	8·9443	4·3089
61	3721	226981	7·8102	3·9365	81	6561	531441	9	4·3267
62	3844	238328	7·874	3·9579	82	6724	551368	9·0554	4·3445
63	3969	250047	7·9373	3·9791	83	6889	571787	9·1104	4·3621
64	4096	262144	8	4	84	7056	592704	9·1652	4·3795
65	4225	274625	8·0623	4·0207	85	7225	614125	9·2195	4·3968
66	4356	287496	8·124	4·0412	86	7396	636056	9·2736	4·414
67	4489	300763	8·1854	4·0615	87	7569	658503	9·3274	4·431
68	4624	314432	8·2462	4·0817	88	7744	681472	9·3808	4·448
69	4761	328509	8·3066	4·1016	89	7921	704969	9·434	4·4647
70	4900	343000	8·3666	4·1213	90	8100	729000	9·4868	4·4814
71	5041	357911	8·4261	4·1408	91	8281	753571	9·5394	4·4979
72	5184	373248	8·4853	4·1602	92	8464	778688	9·5917	4·5144
73	5329	389017	8·544	4·1793	93	8649	804357	9·6437	4·5307
74	5476	405224	8·6023	4·1983	94	8836	830584	9·6954	4·5468
75	5625	421875	8·6603	4·2172	95	9025	857375	9·7468	4·5629
76	5776	438976	8·7178	4·2358	96	9216	884736	9·798	4·5789
77	5929	456533	8·775	4·2543	97	9409	912673	9·8489	4·5947
78	6084	474552	8·8318	4·2727	98	9604	941192	9·8995	4·6104
79	6241	493039	8·8882	4·2908	99	9801	970299	9·9499	4·6261

AREAS AND CIRCUMFERENCES OF CIRCLES UP TO 6 IN. DIAMETER (ADVANCING BY 32NDS AND 16THS).

Dia.	Circum.	Area.	Dia.	Circum.	Area.	Dia.	Circum.	Area.
1/32	·0981	·00077	1 3/8	4·3197	1·4848	3 11/16	11·584	10·679
1/16	·1963	·00307	1 7/16	4·516	1·6229	3 3/4	11·781	11·044
3/32	·2945	·0069	1 1/2	4·7124	1·7671	3 13/16	11·977	11·416
1/8	·3927	·01227	1 9/16	4·9087	1·9175	3 7/8	12·173	11·793
5/32	·4908	·0192	1 5/8	5·1051	2·0739	3 15/16	12·369	12·177
3/16	·589	·02761	1 11/16	5·3014	2·2365	4	12·566	12·566
7/32	·6872	·0376	1 3/4	5·4978	2·4052	4 1/16	12·762	12·962
1/4	·7854	·04909	1 13/16	5·6941	2·5[illegible]	4 1/8	12·959	13·364
9/32	·8835	·0621	1 7/8	5·8905	2·7611	4 3/16	13·155	13·772
5/16	·9817	·0767	1 15/16	6·0868	2·9483	4 1/4	13·351	14·186
11/32	1·0799	·0928	2	6·2832	3·1416	4 5/16	13·547	14·606
3/8	1·1781	·1104	2 1/16	6·4795	3·3410	4 3/8	13·744	15·033
13/32	1·2762	·1296	2 1/8	6·6759	3·5465	4 7/16	13·94	15·465
7/16	1·3744	·1503	2 3/16	6·8722	3·7584	4 1/2	14·137	15·904
15/32	1·4726	·1725	2 1/4	7·0686	3·976	4 9/16	14·333	16·349
1/2	1·5708	·1963	2 5/16	7·2649	4·2	4 5/8	14·529	16·8
17/32	1·6689	·2216	2 3/8	7·4613	4·4302	4 11/16	14·725	17·257
9/16	1·7771	·2485	2 7/16	7·6576	4·6664	4 3/4	14·922	17·72
19/32	1·8653	·2768	2 1/2	7·854	4·9087	4 13/16	15·119	18·19
5/8	1·9635	·3068	2 9/16	8·0503	5·1573	4 7/8	15·315	18·665
21/32	2·0616	·3382	2 5/8	8·2467	5·4119	4 15/16	15·511	19·147
11/16	2·1598	·3712	2 11/16	8·443	5·6723	5	15·708	19·635
23/32	2·258	·4057	2 3/4	8·6394	5·9395	5 1/16	15·904	20·129
3/4	2·3562	·4417	2 13/16	8·8357	6·2126	5 1/8	16·1	20·629
25/32	2·4543	·4793	2 7/8	9·0321	6·4918	5 3/16	16·296	21·135
13/16	2·5525	·5185	2 15/16	9·2284	6·7772	5 1/4	16·493	21·647
27/32	2·6507	·5591	3	9·4248	7·0686	5 5/16	16·689	22·166
7/8	2·7489	·6013	3 1/16	9·6211	7·3662	5 3/8	16·886	22·69
29/32	2·847	·645	3 1/8	9·8175	7·6699	5 7/16	17·082	23·221
15/16	2·9452	·6903	3 3/16	10·014	7·9798	5 1/2	17·278	23·758
31/32	3·0434	·737	3 1/4	10·21	8·2957	5 9/16	17·474	24·301
1	3·1416	·7854	3 5/16	10·406	8·618	5 5/8	17·671	24·85
1 1/16	3·3379	·8866	3 3/8	10·602	8·9462	5 11/16	17·867	25·406
1 1/8	3·5343	·994	3 7/16	10·799	9·2807	5 3/4	18·064	25·967
1 3/16	3·7306	1·1075	3 1/2	10·995	9·6211	5 13/16	18·261	26·535
1 1/4	3·927	1·2271	3 9/16	11·191	9·968	5 7/8	18·457	27·108
1 5/16	4·1233	1·353	3 5/8	11·388	10·32	5 15/16	18·653	27·688

AREAS OF CIRCLES ADVANCING BY 10THS.

Diam.	Areas.										Diam.
	·0	·1	·2	·3	·4	·5	·6	·7	·8	·9	
0	·0	·0078	·0314	·0706	·1256	·1963	·2827	·3848	·5026	·6361	0
1	·7854	·9503	1·1309	1·3273	1·5393	1·7671	2·0106	2·2698	2·5446	2·8352	1
2	3·1416	3·4636	3·8013	4·1547	4·5239	4·9087	5·3093	5·7255	6·1575	6·6052	2
3	7·0686	7·5476	8·0424	8·5530	9·0792	9·6211	10·1787	10·7521	11·3411	11·9459	3
4	12·5664	13·2025	13·8544	14·5220	15·2053	15·9043	16·6190	17·3494	18·0951	18·8574	4
5	19·6350	20·4282	21·2372	22·0618	22·9022	23·7583	24·6301	25·5176	26·4208	27·3397	5
6	28·2744	29·2247	30·1907	31·1725	32·1699	33·1831	34·2120	35·2566	36·3168	37·3928	6
7	38·4846	39·5920	40 7151	41·8539	43·0085	44·1787	45·3647	46·5663	47·7837	49·0168	7
8	50·2656	51·5300	52·8102	54·1062	55·4178	56·5471	58·0381	59·4469	60·8213	62·2115	8
9	63·6174	65·0389	66·476	67·9292	69·3979	70·8823	72·3824	73·8982	75·4298	76·9770	9
10	78·5400	80·1186	81·7130	83·3230	84·9488	86·5903	88·2475	89·9204	91·6090	93·3133	10
11	95·0334	96·7691	98·5205	100·287	102·070	103·869	105·683	107·513	109·359	111·220	11
12	113·097	114·990	116·898	118·823	120·763	122·718	124·690	126·677	128·679	130·698	12
13	132·732	134·782	136·848	138·929	141·026	143·139	145·267	147·411	149·571	151·747	13
14	153·938	156·145	158·368	160·606	162·860	165·130	167·415	169·717	172·034	174·366	14
15	176·715	179·079	181·458	183·854	186·265	188·692	191·134	193·593	196·067	198·556	15
16	201·062	203·583	206·120	208·672	211·241	213·825	216·424	219 040	221·671	224·318	16
17	226·980	229·658	232·352	235·062	237·787	240·528	243·285	246·057	248·846	251·650	17
18	254·469	257·304	260·125	263·022	265·905	268·803	271·716	274·646	277·591	280·552	18
19	283·529	286·521	289·529	292·553	295·598	298·648	301·719	304·805	307·908	311·026	19
20	314·160	317·309	320·474	323·655	326·852	330·064	333·292	336·535	339·795	343·070	20
21	346·361	349·667	352·990	356·328	359·681	363·051	366·436	369·837	373·253	376·685	21
22	380·133	383·597	387·076	390·571	394·082	397·608	401·150	404·708	408·282	411·871	22
23	415·476	419·097	422·733	426·385	430·053	433·737	437·436	441·151	444·881	448·628	23
24	452·390	456·168	459·961	463·770	467·595	471·436	475·292	479·164	483·052	486·955	24
25	490·875	494·809	498·760	502·726	506·708	510·706	514·719	518·748	522·793	526·854	25

METRIC EQUIVALENTS.

1 centimetre . . . = 0·3937 in.
1 sq. centimetre . . . = 0·1550 sq. in.
1 cub. centimetre . . . = 0·0610 cub. in.
1 kilogram . . . = 2·205 lb.
1 kilogram-metre . . = 86·82 in.-lb.
1 centimetre per sec. . . = 0·0328 ft. per sec.
1 gram per sq. centimetre . = 0·0142 lb. per sq. in.
1 gram per cub. centimetre = 62·42 lb. per cub. ft.
Acceleration due to gravity = 32·2 ft. per sec.
" " = 981·4 centimetres per sec.
1 in. . . . . . = 2·54 centimetres.
1 sq. in. . . . . = 6·541 sq. centimetres.
1 cub. in. . . . . = 16·38 cub. centimetres.
1 lb. (avoirdupois) . . = ·4536 kilogram.
1 ft. per sec. . . . = 30·48 centimetres per sec.
1 lb. per sq. in. . . . = 69·34 grams per sq. centimetre.
1 lb. per cub. in. . . = 27·616 grams per cub. centimetre.
1 lb. per cub. ft. . . . = 0·016022 gram per cub. centimetre.
1 in.-lb. . . . . = 1152 gram-centimetres.

EQUIVALENT VALUES OF MILLIMETRES AND INCHES.

Millimetres.	Inches.	Millimetres.	Inches.	Millimetres.	Inches.	Millimetres.	Inches.
1	·0394	27	1·0630	53	2·0866	79	3·1103
2	·0787	28	1·1024	54	2·1260	80	3·1496
3	·1181	29	1·1417	55	2·1654	81	3·1890
4	·1575	30	1·1811	56	2·2047	82	3·2284
5	·1968	31	1·2205	57	2·2441	83	3·2677
6	·2362	32	1·2598	58	2·2835	84	3·3071
7	·2756	33	1·2992	59	2·3228	85	3·3465
8	·3150	34	1·3386	60	2·3622	86	3·3859
9	·3543	35	1·3780	61	2·4016	87	3·4252
10	·3937	36	1·4173	62	2·4410	88	3·4646
11	·4331	37	1·4567	63	2·4803	89	3·5040
12	·4724	38	1·4961	64	2·5197	90	3·5433
13	·5118	39	1·5354	65	2·5591	91	3·5827
14	·5512	40	1·5748	66	2·5984	92	3·6221
15	·5906	41	1·6142	67	2·6378	93	3·6614
16	·6299	42	1·6536	68	2·6772	94	3·7008
17	·6693	43	1·6929	69	2·7166	95	3·7402
18	·7087	44	1·7323	70	2·7559	96	3·7796
19	·7480	45	1·7717	71	2·7953	97	3·8189
20	·7874	46	1·8110	72	2·8347	98	3·8583
21	·8268	47	1·8504	73	2·8740	99	3·8977
22	·8661	48	1·8898	74	2·9134	100	3·9370
23	·9055	49	1·9291	75	2·9528		
24	·9449	50	1·9685	76	2·9922	(100 mm. = 1 decimetre.)	
25	·9843	51	2·0079	77	3·0315		
26	1·0236	52	2·0473	78	3·0709		

KILOGRAMMES IN POUNDS

Kilos	Pounds	Kilos	Pounds	Kilos	Pounds	Kilos	Pounds.
1	2·205	26	57·320	51	112·436	76	167·551
2	4·409	27	59·525	52	114·640	77	169·756
3	6·614	28	61·729	53	116·845	78	171·960
4	8·818	29	63·934	54	119·049	79	174·165
5	11·023	30	66·139	55	121·254	80	176·370
6	13·228	31	68·343	56	123·459	81	178·574
7	15·432	32	70·548	57	125·663	82	180·779
8	17·637	33	72·752	58	127·868	83	182·933
9	19·842	34	74·957	59	130·073	84	185·118
10	22·046	35	77·162	60	132·277	85	187·393
11	24·251	36	79·366	61	134·482	86	189·597
12	26·455	37	81·571	62	136·486	87	191·802
13	28·660	38	83·776	63	138·891	88	194·010
14	30·865	39	85·980	64	141·096	89	196·211
15	33·069	40	88·185	65	143·300	90	198·416
16	35·274	41	90·389	66	145·505	91	200·620
17	37·479	42	92·594	67	147·710	92	202·825
18	39·683	43	94·799	68	149·914	93	205·030
19	41·888	44	97·003	69	152·119	94	207·234
20	44·092	45	99·208	70	154·323	95	209·439
21	46·297	46	101·413	71	156·528	96	211·644
22	48·502	47	103·617	72	158·733	97	213·848
23	50·706	48	105·822	73	160·937	98	216·053
24	52·911	49	108·026	74	163·142	99	218·275
25	55·115	50	110·231	75	165·347	100	220·462

TABLE OF PROPERTIES OF SATURATED STEAM

Absolute Pressure per sq. in.	Temperature of Boiling Point	Weight of 1 cub. ft. of Steam	Volume of 1 lb. of Steam
Pounds	deg. Fahr.	Pounds	Cub. feet.
14·7	212·0	·0380	26·36
15	213·1	·0387	25·85
20	228·0	·0507	19·72
60	292·7	·1425	7·01
65	298	·1538	6·49
70	302·9	·1648	6·07
75	307·5	·1759	5·68
80	312·0	·1869	5·35
85	316·1	·1980	5·05
150	358·3	·3377	2·96
155	361·0	·3484	2·87
160	364·3	·3590	2·79
165	366·0	·3695	2·71
170	368·2	·3798	2·63
175	370·8	·3899	2·56
180	372·9	·4009	2·49
185	375·6	·4117	2·43
190	377·5	·4222	2·37
195	379·7	·4327	2·31
200	381·7	·4431	2·26
210	386	·4634	2·16
220	389·9	·4842	2·06
230	393·8	·5052	1·98
240	397·5	·5248	1·90
250	401·1	·5464	1·83
260	404·5	·5669	1·76
270	407·9	·5868	1·70
280	411·2	·6081	1·64
290	414·4	·6273	1·59
300	417·5	·6486	1·54

INDEX.

A

ACCELERATION forces due to reciprocating parts, 33.
Accumulators, 89 90.
Ackermann steering, 114, 115, 116.
Actuating gear for pumps, *see* Pumps.
Adhesive power, *see* Traction.
Adiabatic law, 22.
Armatures, *see* Magnetos.
Axle, stub, *see* Wheel mountings.

B

BACK axle, 132, 136, 137.
Ball and socket joints, 114.
Ball bearings, engine, 11.
Bearings, main, 17.
— big end, 15-17.
— projected area of, *see* Projected area.
Benzol, *see* Fuel.
Bevel driving gear, 135-137.
Boilers, see Steam generators.
Boyle's law, 21.
Brakes, 129, 131, 132, 133, 137.
Braking forces, 101.
Buffers, *see* Springs.
Burners, *see* Vaporizers.

C

CALORIFIC value of fuel, 60.
Cam shafts, 42.
Cams, construction of, and setting out, 43-47.
Carburetters—
  Arrangement of, on car, 73, 74.
  Automatic extra air type, 66, 67
  Simple form and function of, 61.
  Symptoms, 71, 75
  Variable jet, 68.
Centifrugal pumps, *see* Pumps.
Chain drive, 139
Charging accumulators, *see* Accumulators.
Charles law, 22.
Chassis, definition of, 1
Choke tube, *see* Carburetters.
Clearance or compression volume, 23.
Clutches—
  Cone, 119.
  Hydraulic, *see* Hydraulic gears.
  Inverted cone, 119-121.
  Springs, 120, 121.
Coil clutch, 125.
Compression pressures, 63
— ratio of, 23
Condenser, *see* Magnetos
Cone clutches, *see* Clutches.
Connecting rods, 15.
Contact breaker, *see* Magnetos.
Controlling mechanism, 1.
Cooling systems, air, 91.
— — water, 92, 94.
Countershaft brakes, *see* Brakes.
Crank effort, *see* Torque, 35.
— cases, 11.
— pins, 17.
— shafts, 16.
Cut off, *see* Steam engines.
Cycle of operations, *see* Engines.

Cylinders—
  Construction of, 8, 9, 10, 11, 57, 71, 72, 92, 96.
  With detachable heads, 50

D

Darracq engine, see Valves
Detachable heads, see Cylinders
Differential, 133, 134.
-- bevel, 135, 137.
- spur, 136.
Disk clutches, 124, 125.
Distributors, see Magnetos.
Drag link, see Steering gear.
Dynamometer, absorption, 31

E

Eccentric, 148.
Electric transmission systems, 158, 159.
Engines—
  Construction, 9, 19, 20.
  Cycle of operation, 7
  Darracq, see Valves.
  Four-stroke cycle, 7.
  Knight, ,,
  Perrot, ,,
  Two-stroke cycle, 56.
  Valveless, 57 58, 59.
Epicyclic gear, 130.
Exhaust pipes, see Cylinders
Expanding brakes, see Brakes.

F

Fans, 19, 92, 96.
Feed water heaters, 141.
Fire tube boilers, see Steam generators.
Flash generators, see Steam generators.
Float chamber, see Carburetters.
Floating axle, see Back axle.
Fly-wheel, 18, 37, 96.
Frame—
  Fittings, 111.
  Force diagram, note on, 11[illegible]
  Main, 103, 106.
  Subsidiary, 106.
Freezing point—
  Mixture water and glycerine, 97.
  Water, 96.
Friction drive, 153, 155.
Front axle, 111.
Front springs, see Springs.
Fuels—
  Chemistry of, 60, 61.
  Flash point, 63.
  Heating value of, 60, 61.
Fusible plug, see Steam generators.

G

Gases, properties of, 21 23.
— control of, see Valve settings.
- quantity of, and velocity of, 18.
Gate change, 127, 128, 129.
Gears and gear boxes, 125.
Gear levers, 127, 128, 129.
Gudgeon pin, 13.

H

Heat, radiating, see Cooling systems, radiators, pumps.
Heat values, see Fuels.
Hele-Shaw clutch, see Disk clutches.
Helical pump, see Pumps.
Hewitt piston valve engines, see Valves.
Hindley worm, see Worm-driving gear.
Hopkinson indicator, see Indicators, optical.
Horse-power, indicated, 29.
— — brake, 30.
— — formulæ, 32.
Hydraulic gear, 105, 155, 15

IGNITION, *see* Magnetos accumulators.
Indicator diagrams, 24, 25, 146.
Indicators, optical, 28.
Induction pipe, *see* Cylinders.
Instantaneous centre, 111, 115.
Inverted cone clutches, *see* Clutches.
Irreversible gearing, 117.
Isothermal law, 22.
Itala engines, *see* Valves.

J

JOINT knuckle, *see* Knuckle joint.
— universal, *see* Universal joint.

K

KNIGHT sleeve valve, *see* Valves.
Knuckle joints, 112, 113, 114.

L

LANCHESTER worm, *see* Worm driving gear.
Lay shaft, 127.
Leather cone clutch, *see* Clutches.
Levers brake, *see* Brakes.
— engine control, *see* Steering column.
— gear, *see* Gear levers.
Link motion, *see* Valve gear, Steam engine.
Load on wheels, *see* Traction.
Locomotive brakes, *see* Brakes.
Lubrication—
  Combined splash and pressure, 79.
  Object of, 77.
  Pressure, 78.
  Pumps for, *see* Pumps.
  Splash, 77.

MAGNETOS—
  Armature, 82, 83
  Condenser, 84, 85
  Contact breaker, 84, 85, 87
  Distributor, 84, 85, 86.
  Locating troubles, 88, 89.
  Magneto, 82.
  Spark gap, 85, 87.
  Timing, 86.
  Wiring diagram, 85.
Mixing chamber, *see* Carburetters
Mixture, *see* Carburetters.
Multiple disk clutches, *see* Disk clutches.
Mushroom valves, *see* Valves

O

OIL sump, *see* Lubrication

P

PARAFFIN, *see* Fuels.
Pedals, brake, 123, 132, 133.
— clutch, 123, 132, 133.
Permanent magnets, *see* Magnet.
Petrol, *see* Fuels.
Pilot burner, *see* Vaporizer
Pin gudgeon, *see* Gudgeon pin.
Pipes, *see* Cylinders.
Pistons—
  Assembling, 93.
  Construction, 11, 77.
  Valves, *see* Valves.
Plate clutches, *see* Disk clutches.
Plug valves, *see* Valves.
Plunging joint, *see* Universal joint.
Poppet valves, *see* Valves.
Power plant, 1.
Pressure, indicating, *see* Indicator diagrams.
— mean, effective 25

Projected area, bearings, 17.
— — pistons, 26.
Pumps—
  Centrifugal, 93.
  Diaphragm, 94
  Eccentric disk, 93.
  Geared pinion, 79, 80.
  Helical, 94
  Piston or plunger, 81

Q

QUADRANT change mechanism, *see* Gears and gear boxes; gear levers.

R

RADIATORS, 92, 95
Radius rods, 138.
Ratio of compression, 23.
Rear springs, *see* Springs.
Resistances to motion, 101.
Roots blower, *see* Pumps (geared pinion).
Rotary disk, *see* Valves.
— valve, *see* Valves.

S

SAFETY valve, 143.
Screw and nut gear, 117, 118.
— pumps, *see* Pumps.
Selector rods, *see* Gate change.
Sleeve valves, *see* Valves.
Sliding piston valves, *see* Valves.
Spark gap, *see* Magnetos.
Speed gears, *see* Gears and gear boxes.
Springs—
  Anchorage, *see* Frames.
  Buffers, 109.
  Formula, 107, 111, 113.
  Front, 108, 112, 113.
  Rear, 108, 112, 113.
  Supplementary, 110.
Springs clutch, *see* Clutches.
Starting handles, 18.
Steam engine, 144, 151.
— generators, 141, 144.
— properties of, 140.
Steering arms, *see* Steering gear.
— column, 2, 3, 113, 116, 118.
— gear, 112, 113, 122, 123.
Stub axle, *see* Wheel mountings.
Superheated steam, 140.
Supplementary springs, *see* Springs.
Suspension three-point, *see* Three-point suspension.

T

THERMO syphon cooling, *see* Cooling systems.
Three-point suspension, 1[illegible]7.
Throttle valve, action of, 66.
Timing, *see* Valve settings, magnetos.
Torque—
  Diagram, 36.
  Obtaining by calculation, 35.
  — graphically, 35, 37.
Torque members, 109, 138.
Traction, adhesive power, 98, 99, 100.
Transmission gearing, 1.

U

UNIVERSAL joints, 123, 129, 134.

V

VALVE gear, steam engine, 148, 151.
— settings, 44, 45, 48.
Valveless, *see* Engines.

Valves—
  Arrangement, 4
  Cams for, *see* Cams.
  Guides, 46.
  Pistons, 55.
  Poppet, 39, 40.
  Rotary plug, 53.
  Seatings, 39.
  Sleeve, 49.
  Springs, 40.
  Tappets, 46.
Vaporizer, 142.

W

Water paper, *see* Cylinders.
Weston clutch, *see* Disk clutches.
Wheel mounting, 111, 112, 113, 137.
Wiring diagram, *see* Magnetos.
Work, definition of, 23.
Worm and sector gear, *see* Irreversible gearing.
— driving gear, 136.

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